Design for Managing Obsolescence
A Design Methodology for Preserving Product Integrity in a Circular Economy

den Hollander, Marcel

DOI
10.4233/uuid:3f2b2c52-7774-4384-a2fd-7201688237af

Publication date
2018

Document Version
Final published version

Citation (APA)
den Hollander, M. (2018). *Design for Managing Obsolescence: A Design Methodology for Preserving Product Integrity in a Circular Economy*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:3f2b2c52-7774-4384-a2fd-7201688237af

DESIGN FOR MANAGING OBSOLESCENCE

A Design Methodology for Preserving Product Integrity in a Circular Economy

Dissertation by
MARCEL DEN HOLLANDER

DESIGN FOR MANAGING OBSOLESCENCE

A Design Methodology for Preserving Product Integrity in a Circular Economy

Dissertation
for the purpose of obtaining the degree of doctor at Delft University of Technology
by the authority of the Rector Magnificus, prof. dr. ir. T. H. J. J. van der Hagen
chair of the Board for Doctorates
to be defended publicly
on Friday 15 June at 12:30 o'clock

by

Marcel Cornelis DEN HOLLANDER
Ingenieur Industrieel Ontwerpen, Delft University of Technology, the Netherlands
born in The Hague, the Netherlands

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus,	chairman
Prof. dr. ir. C. A. Bakker	Delft University of Technology, promotor
Prof. dr. H. J. Hultink	Delft University of Technology, promotor

Independent members:

Prof. dr. h.c. W. R. Stahel	University of Surrey, United Kingdom
Prof. dr. T. H. Cooper	Nottingham Trent University, United Kingdom
Prof. dr. M. Halme	Aalto University Business School, Finland
Prof. dr. E. J. Nijssen	Eindhoven University of Technology
Prof. dr. A. R. Balkenende	Delft University of Technology
Prof. ir. J. E. Oberdorf	Delft University of Technology, reserve member

This research has been funded by the Innovation-Oriented Research Program 'Integrated Product Creation and Realization (IOP-IPCR) of the Netherlands Ministry of Economic Affairs, facilitated by the Netherlands Enterprise Agency (RVO) and the ResCoM (Resource Conservative Manufacturing) project, a European Commission co-funded project working to develop an innovative methodology and software platform for the industrial implementation of closed-loop manufacturing systems by 2017.

Title: DESIGN FOR MANAGING OBSOLESCENCE
A Design Methodology for Preserving Product Integrity in a Circular Economy
ISBN 9789082873603 Design by Yvo Zijlstra
Published by Marcel den Hollander IDCR
Printed by ProefschriftMaken || www.proefschriftmaken.nl

Doctoral dissertation, Delft University of Technology, Delft, the Netherlands

Over 10,000 years humans have been remarkably successful at envisioning and instigating change in an attempt to improve the human condition. However, it seems that in the last century or so, we have become too skilled at these activities for our own good.

To my family, with immense gratitude for the past and present and with hope and anticipation for the future.

TABLE OF CONTENTS

In my more than 20 years as a practicing industrial designer, I have learnt that many, potentially promising, ideas for sustainable design end up unused – or are not even considered in the first place – if they are not accompanied and supported by a business rationale for adopting such an idea.

PREFACE

Much of the literature on sustainability and sustainable product design seems permeated by the belief that it is Mother Earth who needs saving. This widespread misconception presents a major barrier to the transition to a circular economy. Mother Earth might at some point in the future no longer look the way we want her to, and for a cosmic blink appear to have lost her ability to sustain human life, but she will continue to live on long after the last human has walked the face of the planet. As a matter of fact, some might even say she is better off without us.

Blessed with a sufficiently large brain and opposable thumbs, we humans, as a playful, curious and tool wielding species, have for over 10,000 years been remarkably successful at envisioning and instigating change in an attempt to improve the human condition. However, it seems that in the last century or so, we have become too skilled at these activities for our own good. Recklessly leveraging the power of fossil fuels and fanning the flames of human desire, we are currently using up natural resources and polluting our world at such a dazzling rate that the same processes that were originally meant to enhance our chances of survival have instead become a threat to it. The challenge we are currently facing is therefore not how to save Mother Earth, but rather how to bring the industrial and economic processes we have unleashed under control and make them work again for *our* long-term survival, preferably in such a way that it doesn't require us to renounce our innate desire for new experiences and our love for toys and tools that makes us so human.

As an industrial designer, I have always worked from the belief that well-designed products can help enhance the quality of our lives and give expression to who we are (or want to be). Material artefacts have always been and will always be an integral part of human culture. But to keep our products from destroying us, especially in light of the expected growth in world population and demand, I also think we need to learn to contain their – what in our present throwaway society often seems – all-consuming power over us, just as we have learned to contain the all-consuming power of fire thousands of years ago.

In my more than 20 years as a practicing industrial designer, I have learnt that many, potentially promising, ideas for sustainable design end up unused – or are not even considered in the first place – if they are not accompanied and supported by a business rationale for adopting such an idea. The circular economy concept in that respect seems promising, as it aims to limit the flows of materials and energy into and out of the economic system at levels that in principle can be tolerated and sustained indefinitely by nature whilst protecting the capacity of the economic system to create wealth. I hope that the concept of managing obsolescence and the new design methodology for managing obsolescence in a circular economy that are presented in this thesis will inspire industrial designers (and other business professionals) to explore and discover new ways to contribute in doing so[1].

1. *In the remainder of this thesis, I will use the pronoun "we" instead of "I" when describing specific research activities. The first reason for this is to reflect that, although the thesis is the result of my own work, my supervisors and others have helped me throughout the study to achieve this result. The second reason is that the pronoun "we", in my opinion, makes for more pleasant reading.*

What design methodology can help industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?

SUMMARY

This thesis is about the development of a design methodology that can help industrial designers to design products with a long or extended lifetime in support of a circular economy. The research is presented from an industrial design perspective.

CHAPTER 1: INTRODUCTION
Material resources are the lifeblood of the industrial economy. Since the start of the Industrial Revolution, the rate at which the economy uses up natural resources and produces waste through the production and consumption of products has been steadily increasing to the point of becoming critical from an environmental (pollution) and economic (supply) point of view. Many options to reduce the consumption of resources and the production of waste have been conceived and tried with varying levels of success. These range from policy and legal to market incentives and attempts to influence consumer behaviour. The most promising option, both from an environmental and from an economic perspective, to limit the rate at which we use up natural resources, is to reduce – and preferable minimize – the flux of non-renewable energy and (natural) resources into and out of our economic system. This can be done by preserving as much of the economic value embedded in our products as possible, in a systematic manner and preferably many times over. It is this notion that lies at the heart of the circular economy concept, an idea that has in recent years been embraced by the European Commission and is rapidly gaining momentum in the scientific community and wider society. The aim of a circular economy is to limit the flows of materials and energy into and out of the economic system at levels that in principle can be tolerated and sustained indefinitely by nature whilst protecting the capacity of the economic system to create wealth. In a circular economy, the economic and environmental value of materials is preserved by keeping them in the economic system for as long as possible, preferably by lengthening the useful lifetimes of products formed from them and, when lifetime extension at product level is no longer possible for environmental or economic reasons, by looping products back into the manufacturing process so their constituent materials can be reused. The notion of *waste* no longer exists in a circular economy because products and materials are, in principle, reused and cycled indefinitely. It follows that product lifetime extension – not instead of but in addition to materials recycling – and the ability to create, deliver and capture economic value from long or extended product lifetimes are essential to a circular economy. Industrial design has the potential to contribute significantly to achieving the goals of a circular economy because the design of a product directly affects the characteristics of the physical product as well as the structure of the entire value chain.

The thesis belongs to the scientific discipline of design research and, within this larger discipline, focuses on the domain of sustainable design, i.e., that segment of industrial design that in the creation of products and systems intentionally takes on the additional responsibility of *"balancing economic, environmental and social aspects"* (Charter & Tischner, 2001, p. 121) with the end goal of fostering and safeguarding lasting human well-being.

The field of sustainable design originated in eco-design. Eco-design is the systematic integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle. As the field of sustainable design evolved, its scope gradually enlarged. Where eco-design is primarily con-

cerned with resource flows, sustainable design has also come to include aspects such as social sustainability, for instance. As the thesis takes a material flows perspective on the circular economy, it compares product design for a circular economy with eco-design (but not with sustainable product design). As part of the domain of sustainable product design, the discipline of eco-design is well developed and recognized. It provides product designers with a design methodology, i.e., a range of guiding principles, eco-design strategies, and methods, for systematically integrating environmental aspects into product design with the aim to improve the environmental performance of the product throughout its whole life cycle. The thesis argues, however, that there is a fundamental distinction to be made between eco-design and product design for a circular economy, i.e., circular product design, and that this means that circular product design requires a new, or at least an adapted, design methodology.

The most important difference between eco-design and circular product design is of a methodological nature. The current design methodology (i.e., guiding principles, strategies, and methods) for product lifetime extension as proposed by eco-design is rooted in the here and now (which is the linear economy). It is aimed at mitigating the effects of current problems (e.g., waste as a by-product of creating wealth) and as such is an example of what is known in the literature as a *relative* approach to sustainability. But how can industrial designers come up with truly sustainable or circular innovations if the current methods only lead them to optimize what is already there? By contrast, circular product design starts from *"an idealised end state"* (Faber, Jorna & Van Engelen, 2005, p. 3) (i.e., creating wealth without creating waste) and systematically works back and forth to close the gap between there and here. As such, it is an example of what is known in the literature as an *absolute* approach to sustainability. Although absolute approaches have been viewed by many as utopian, impractical, and unnecessarily normative, they could prove advantageous over and complementary to relative approaches to sustainability for two reasons. The first is that because absolute approaches imply notions of an ideal state (i.e., a circular economy without waste as an ideal state), they can challenge industrial designers to strive for such an ideal state, thus opening up a wider solution space and an increased likelihood of finding innovative solutions. This could lead to new solutions that may not be evident or considered viable when the problem is viewed from a relative, in this instance linear economy, perspective but which emerge only when the problem is allowed to be considered in a different and wider (socio-economic) context. The second reason is that, because of its widened perspective, an absolute approach can help industrial designers avoid unintended adverse effects of their interventions that could occur if underlying, and often more systematic, problems are left unaddressed.

Over the past six decades, the field of eco-design has for example framed product lifetime extension mainly from a resource efficiency perspective, largely ignoring the business implications ushered in by the circular economy concept. Notwithstanding its usefulness for reducing the environmental impact of products, the eco-design approach has left largely unexplored the interaction between (the design of) long-life tangible products and their business-economic context. As a consequence of this rather narrow way of framing product lifetime extension – i.e., focused on tangible products and resource efficiency – limited attention has been given to the development of a design methodology explicitly aimed at leveraging the interactions between (the design of) physical products and their business-economic context to systematically increase, let alone optimize, product lifetimes. With the recent increase in attention paid to the circular economy concept and its adoption by the EU, the resulting knowledge gap has gained significance and needs to be addressed, as the economic and environmental success of the circular economy concept hinges on its ability to leverage the above interactions.

Taking an absolute perspective on sustainability to the circular economy concept, this thesis therefore sets out to develop a design methodology for designing products with a long and/or extended product lifetime in a circular economy with the intention to help fill this knowledge gap. Accordingly, the main research question of the thesis is:

"What design methodology can help industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?"

To arrive at an answer to the above research question, the thesis is divided in two main parts in which a number of sub-research questions are subsequently addressed. The first part, chapter 2 through chapter 4, aims to establish a theoretical framework for the development of a new design methodology that is presented in the second part, chapter 5 through chapter 6. (As the thesis, due to its cross-disciplinary nature of its subject, reviews literature from multiple scientific domains, a set of appendices is furthermore included after the main text to provide background information for those readers who may be familiar with concepts from some of these domains but less so with concepts from others.)

PART ONE

CHAPTER 2: PRESERVING PRODUCT INTEGRITY aims to provide an answer to sub-research question A: "How can product lifetime extension in a circular economy be defined within the context of industrial design?" The chapter reviews the literature on resource states and interventions for product lifetime extension and creates a comprehensive overview of the key concepts and terms that are considered relevant for industrial designers when designing for long and extended product lifetimes in a circular economy. This chapter defines product lifetime in terms of obsolescence, thereby making it clear that product lifetime is not merely an engineering quality that can be designed into products but is also affected by intangible factors like user behaviour and wider socio-cultural influences. Given these many factors potentially affecting product lifetime, chapter 2 argues that industrial designers cannot design products with a long or extended lifetime but can only design *a potential for* a long or extended lifetime into products. The degree to which this potential is actually realized is determined to a large extent by factors *other* than the design of the physical products or systems, such as the socio-economic context of the product (e.g., the business model that the product is embedded in).

In addition, chapter 2 presents new definitions of interventions for product lifetime extension and introduced the concepts of *presource*, *recovery horizon* and *leakage* to accommodate the absence of the concept of waste in a circular economy. Adopting the order indicated by Stahel's (2010) Inertia Principle allows the chapter to develop a new typology for interventions for preserving product integrity. Based on this typology for interventions for preserving product integrity, chapter 2 concludes its proposed answer to sub-research question A with the presentation of a typology for eight design approaches for preserving product integrity. This typology is shown in figure S.1 and forms the starting point for chapter 3.

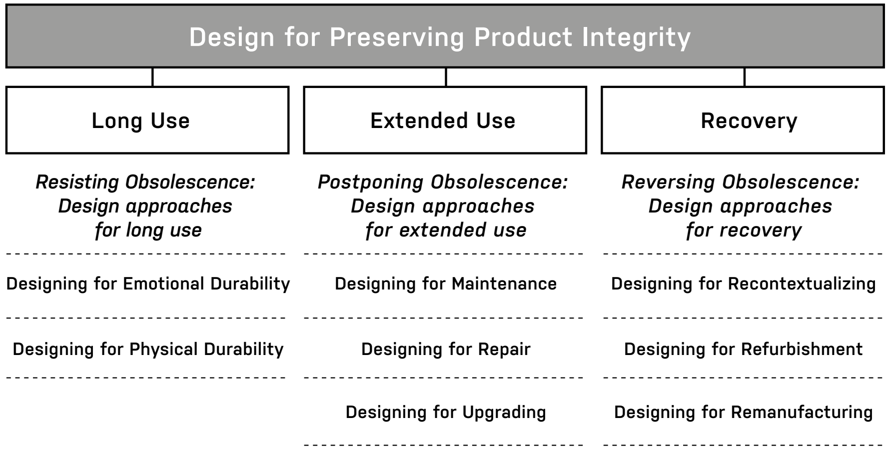


Figure S.1: A typology for design approaches for preserving product integrity in a circular economy.

CHAPTER 3: DESIGNING FOR PRESERVING PRODUCT INTEGRITY aims to provide an answer to sub-research question B: "What guiding principles and design interventions can industrial designers use when designing for long and extended product lifetimes in a circular economy?" The chapter takes the typology of approaches of design for preserving product integrity presented at the end of chapter 2 as a starting point and sets out to develop the abstract design approaches into practical and actionable design strategies for preserving product integrity by reviewing the literature in search of design interventions that industrial designers can select and apply to support the various design approaches for preserving product integrity. This chapter introduces the distinction between design directions (e.g., resisting obsolescence, postponing obsolescence and reversing obsolescence), design approaches (e.g., designing for physical durability, designing for emotional durability, designing for maintenance, etc.), design principles (e.g., material selection, dis- and reassembly, modularization, identification) and design strategies (e.g., design for physical durability, design for emotional durability, design for maintenance, etc.). The distinction between design approaches and design strategies is necessary as the chapter finds that virtually all of the design approaches for preserving product integrity from the typology developed in chapter 2 are supported by the same set of underlying design principles. This leads to two important insights. The first insight is that the design principles selected by industrial designers in support of a particular design approach will also affect other design approaches. To make industrial designers aware of the notion that the design principles selected in support of a particular design approach more often than not also affect other design approaches, chapter 3 introduces the concept of a three-dimensional design space for preserving product integrity, as shown in figure S.2.

By plotting existing products in this design space based on an assessment of the relative importance of the three design directions for preserving product integrity in the overall design intention of a product, industrial designers can use the design space for preserving product integrity as a tool to compare product designs and increase their understanding of what it means to design for different design directions and intentions for preserving product integrity.

The second insight is that the application of the design approaches (and underlying design principles) is heavily dependent on business context, i.e., the particular business objec-

Figure S.2: Example products plotted in the three-dimensional design space for preserving product integrity. The three dimensions are formed by the three design directions for preserving product integrity: resisting obsolescence, postponing obsolescence and reversing obsolescence.

tive(s) the design approaches are intended to help achieve. Chapter 3 finds that the business context (e.g., business and product strategy) of a product to a large extent determines how a particular design approach should be materialized. For instance, the requirements for, and the desired end result of, design for repair are different for a company that wants to retain control and have repairs exclusively performed by qualified service personnel than for a company that wants to promote repair by the users of their products. Design principles such as accessibility need to be interpreted differently by industrial designers in each of these examples depending on the particular business context (e.g., restricting access in the former and facilitating access in the latter instance). Building on this insight, chapter 3 concludes that the eight design approaches only provide practical guidance to industrial designers, i.e., only become actionable design strategies, when they are considered in conjunction with the business context of the product. For this reason, the chapter proposes to make the business context an integral part of the definition of the eight design strategies (i.e., design for emotional durability, design for physical durability, design for maintenance, design for repair, design for upgrading, design for recontextualizing, design for refurbishment and design for remanufacturing) that are presented in chapter 3.

CHAPTER 4: CREATING AND CAPTURING VALUE FROM PRODUCT INTEGRITY aims to provide an answer to sub-research question C: "What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?" The chapter reviews the literature with the aim of creating a typology of circular business models for preserving product integrity in a circular economy. The chapter introduces the concept of a circular business model for preserving product integrity and establishes three criteria that business models have to meet in order to qualify as such: 1) They must be built around tangible products, 2) preserving product Integrity must be essential to their continuity, revenue and profit and 3) they must be circular.

Chapter 4 develops a new typology for circular business models for preserving product integrity, consisting of three product-service based business model types: The Classic Long Life Model, the Access Model and the Performance Model. In addition, the chapter identifies three additional business model types that create and capture value from preserving product integrity but do not qualify as circular business model types for preserving product integrity. Strictly speaking, the Hybrid Classic Long Life Model, and the Hybrid Access Model do not qualify as circular business model types for preserving product integrity as their main revenue streams rely on short-lived consumables rather than long-lived durables. However, depending on how the resource loops for the consumables are set up in specific instances, they could qualify as circular business models and as such play an important role in (the transition towards) a circular economy. Business models of the third type, i.e., Gap Exploiters, not only fail to qualify as a circular business model type for preserving product integrity but can also never qualify as a circular business model at the instance level as they (by definition) have no control over the design of the products whose lives they extend. The Gap Exploiter Model is included in the chapter as it can play an important role in the transition to an absolute circular economy.

PART TWO

Using data and insights gathered from the literature and company interviews and visits, Part Two brings together the separate elements from the theoretical framework established in Part One with the end-goal of developing a new methodology for designing products with a long or extended lifetime in a circular economy.

CHAPTER 5: MANAGING OBSOLESCENCE aims to provide an answer to sub-research question D: "What guiding principles and management strategies can businesses use when creating, delivering and capturing value from long and extended product lifetimes in a circular economy?" The objective of chapter 5 is to identify or develop guiding principles and management strategies for circular business models for preserving product integrity as these determine the objectives that design strategies for preserving product integrity should help achieve. Based on the current literature, chapter 5 identifies maximizing business model circularity as the unique additional business goal that sets circular business model types for preserving product integrity apart from business model types for long and extended lifetimes in a linear economy. The chapter identifies two key barriers to maximizing business model circularity: 1) Random fluctuations in the flow of obsolete products, and 2) a mismatch between the actions required for achieving environmental and economic business objectives. Next, the chapter focuses on how circular business models for preserving product integrity could surmount the first key barrier, i.e., how circular business models for preserving product integrity could maximize their level of control over the flow of obsolete products. As the current literature contains only approaches for *affecting* the flow of obsolete products but none for *controlling* the flow of obsolete products, chapter 5 introduces the concept of *managing obsolescence* as a new management and design approach for supporting the creation, delivery and capture of value from long and extended product lifetimes in a circular economy. During the development of the concept of managing obsolescence, a gap is identified in the current literature: it does not provide insight into the factors within companies that play a role in successfully manufacturing and marketing long-life products – other than the design of the tangible product – that could potentially be leveraged by industrial designers (and other business professionals) to control the flow of obsolete products. To gain insight into the workings (and challenges) of companies currently marketing and manufacturing long-life products and (partly) fill this gap, five company interviews and two, multi-day, company visits are conducted. The outcomes of the interviews and company visits make clear that, apart from the design of the tangible product, many other factors – such as the type of right to the product traded, brand identity, company culture, contractual agreements, (relationships with) suppliers, (relationships with) employees, (relationships) with customers, level and type of service, channels, rules and regulations, internal organizational structure, i.e., elements from virtually the entire structure of the business model – affect the feasibility and success of manufacturing and marketing products with a long or extended lifetime and should therefore be taken into consideration when planning for managing obsolescence. The essence of managing obsolescence lies in the fact that successfully preserving product integrity is not achieved by preserving functionality over time (i.e., a tangible product design and engineering task) alone but instead relies on preserving perceived value over time (i.e., a combined task of tangible product design and engineering and the marketing function).

CHAPTER 6: A DESIGN METHODOLOGY FOR MANAGING OBSOLESCENCE, building and expanding on the answer to sub-research question D presented in chapter 5, develops a methodology for design for managing obsolescence and, as part of the process, provides an answer to sub-research question E: "To what extent are some combinations of design interventions and business model types more likely to be successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?"

The new design methodology for managing obsolescence consists of five new design methods and is intended to enable industrial designers to tailor their product designs to circular business model instances for preserving product integrity that strive to maximize the circularity of their business model. It is different from – and adds to – existing design methodology for (sustainable) product design for products with a long and/or extended lifetime in that it takes into account the design of the tangible product as well as the design of the overall value proposition(s) and the business model(s) supporting said value proposition(s) over the entire lifetime of the product time. In addition to (and making use of) the design method of the three-dimensional design space for preserving product integrity introduced already in chapter 3, chapter 6 introduces four new design methods in support of design for managing obsolescence: (the development of) an *obsolescence profile*, (the development of) a *longitudinal value proposition*, the development of a *longitudinal business model* and the *heuristic framework for design for managing obsolescence*. The obsolescence profile for a product describes the predetermined sequence covering the entire lifetime of a product that lists the point(s) in time when, and the way(s) in which, a product will be prevented from becoming obsolete and/or will become obsolete and subsequently will be recovered. As such, it captures the predetermined series of use cycles (e.g., number and duration) of a product that would enable a circular business model for preserving product integrity to maximize business model circularity (defined by the thesis as the fraction of economic value added to (p)resources that is preserved over time) for this product. As the properties of the product can, however, vary between use cycles (e.g., a refurbished product is different from a new product), the contribution of the tangible product to the overall value proposition it is embedded in is likely to differ accordingly. For example, whereas a new smartphone can be offered as part of a premium priced service plan, a refurbished phone would most likely require a service plan with discounted rates to result in an attractive and viable value proposition.

The longitudinal value proposition describes the predetermined set of value propositions in which changes in the properties of the tangible product along the obsolescence profile are compensated by, for example, changes in pricing and/or service levels as required over a product's entire lifetime, i.e., along its obsolescence profile.

The longitudinal business model describes the predetermined set of business models that matches the longitudinal value proposition along the obsolescence profile, as in some instances the different value propositions need different business models to support them (e.g., different channels, different key partners). The heuristic framework for design for managing obsolescence is intended to aid industrial designers in meeting the new challenges posed by designing for managing obsolescence in a circular economy (i.e., designing in the *temporal* dimension as well as in the spatial dimension and selecting design directions in conjunction with circular business models for preserving product integrity) by providing guidance to industrial designers (and other business professionals) in selecting design directions and circular business model types for preserving product integrity when developing obsolescence profiles, longitudinal value propositions and longitudinal business models. For lack of theoretical and empirically validated data in the extant literature as to which particular combinations of design directions and PSS-based (circular) business model types are successful, the heuristic framework is constructed from inferences. Although these inferences are the result of careful reflection in the light of the secondary data and the authors' 20 years industry knowledge, they are made on the basis of incomplete (e.g. not taking into account the effects of product type) and non-validated information. Therefore, the heuristic framework as shown in figure S.3 is presented in chapter 6 as a conceptual proposition. As a consequence, the version of the heuristic framework as currently presented should be considered generic and recognized as having limited predictive value. A comparison between the predictions for successful combinations of design directions and circular business models from the heuristic framework and those found in twelve existing products for example, yields perfect and close matches as well as some discrepancies. The predictive value of the heuristic framework as presented in chapter 6, however, is secondary. The primary purpose of the heuristic framework for design for managing obsolescence as presented in chapter 6 is twofold: Firstly, it serves to illustrate how the author envisions a method for design for managing obsolescence that integrally captures and communicates the varying extent to which different combinations of design directions and circular business model types can be expected to be successful as a result of different product types, life cycle stages and circular business model types, with the aim of providing guidance to industrial designers (and other business professionals) in selecting design directions and circular business model types when designing for managing obsolescence. Secondly, it highlights a gap in the literature with regard to the extent to which a combination of design directions and circular business models can be expected to be successful and, as such, indicates the need for further research should there be a desire to make concept of managing obsolescence and the design methodology for managing obsolescence operational as part of (the transition to) an absolute circular economy.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS presents the main conclusions of the study which are summarized here.

In answer to the main research question – "what design methodology can help industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?" – the thesis argues that in order to increase the likelihood that product lifetime extension in a circular economy will be successful from both an environmental and an economic perspective, industrial designers need to be able to control not only the spatial dimension (materialization and geometry) of products, but also the *temporal* dimension. This temporal dimension is related

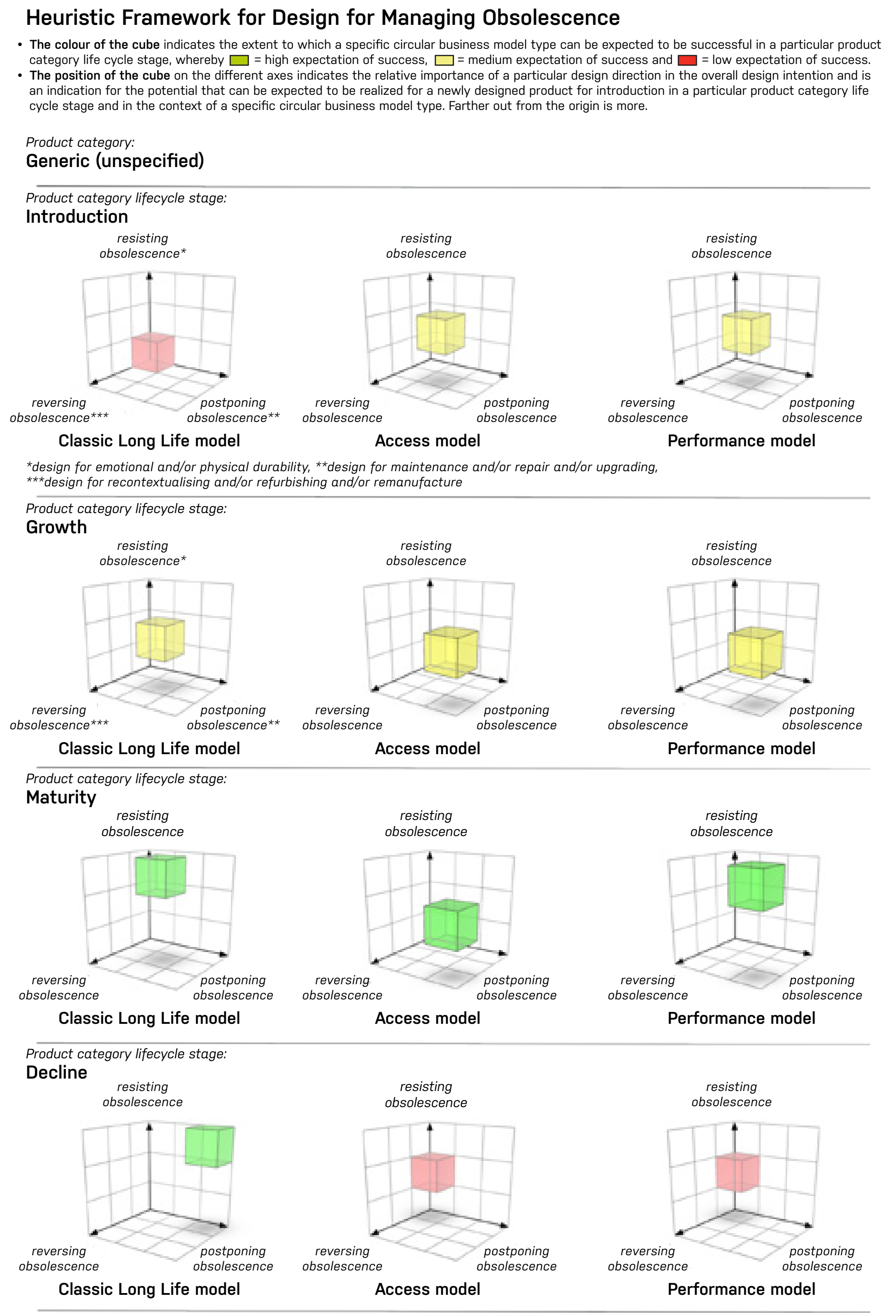


Figure S.3: A heuristic framework for design for managing obsolescence based on the inferences presented in sub-section 6.4.2.

to the number and duration of product use cycles and the duration of total product lifetime. To enable industrial designers to capture this temporal dimension, the thesis presents:

- a new design methodology: design for managing obsolescence;
- five new design methods and two typologies in support of managing obsolescence;
- insight into (the factors determining) how and when to best apply these methods;
- insight into where and in collaboration with whom to apply these methods in the product innovation process.

One of the most important insights gained from the development of the design methodology for managing obsolescence is that managing obsolescence should not be considered a *one-size-fits-all* approach, but that (design for) managing obsolescence instead requires the careful crafting of *tailor-made* solutions that, in order to be successful, must take into account factors like product type, product (sub-)category lifecycle stage, circular business model types and cultural preferences and managerial (e.g., strategic) considerations over the entire product lifetime. The design methodology for managing obsolescence as presented in this thesis offers (conceptual propositions for) methods to industrial designers that are intended to help them work with the above factors and to get a better grip on their effects on requirements for the design of the tangible product when developing such *tailor-made* solutions.

As (the design methodology of) managing obsolescence implies that tangible products are iteratively co-designed in conjunction with obsolescence profiles, longitudinal value propositions and longitudinal business models, the role of industrial designers will change from a predominantly operational to a more business strategic one. This will require industrial designers to work together more closely with professionals from other, presently already more strategically inclined, business functions such as marketing and familiarize themselves with some aspects of the theory and terminology from the business sciences. The latter may seem a daunting prospect at first but will ultimately increase the importance of the industrial designer's role and skills.

For (design) researchers, the design methodology of managing obsolescence offers a structure to interpret, re-evaluate and/or leverage the results of past and current research on product lifetimes and product lifetime extension as well as an outline of opportunities for future research, for example increasing the predictive capacities of the heuristic framework for design managing obsolescence by refining it and/or creating different versions for specific product categories or industries or deepening insights into the application of individual design principles specifically from a product lifetime perspective. As product lifetime extension or preserving product integrity has only limited relevance in a linear economy as compared to in a circular economy, there are many aspects of product lifetime extension that have been researched in the past, but never evaluated in the context of managing obsolescence, such as research on reliability, maintenance and dis- and reassembly.

The same can be said for insights acquired from decades of design and marketing research. In a linear economy, many of these insights have mainly been used to motivate consumers to swiftly acquire new or quickly replace their old products. When re-evaluated in the context of managing obsolescence, these insights could perhaps provide new information on how consumers could be motivated to hold on to their products longer, potentially complementing extant work on this topic.

For business professionals involved with manufacturing and marketing tangible, and durable, products, managing obsolescence means that they need to rethink their current business models, as these – most probably – are based on repeated product sales and not designed to profit from preserving product integrity.

The design methodology for managing obsolescence presented in the thesis was developed *based upon theory* and has not been tested or validated empirically. As such, it is in need of future validation before it could be made operational. However, these tasks are considered to lie outside the scope of the present thesis.

REFERENCES SUMMARY:

Charter M., & Tischner U. (2001). Sustainable Solutions. Developing Products and Services for the Future. Sheffield, UK: Greenleaf.
Faber, N., Jorna, R., & Van Engelen, J. O. (2005). The Sustainability of "Sustainability"—A Study into the Conceptual Foundations of the Notion of "Sustainability". *Journal of Environmental Assessment Policy and Management, 7*(01), 1-33.
Stahel, W. R. (2010). *The Performance Economy (2nd ed.)*, Hampshire, UK: Palgrave Macmillan Hampshire.

1

INTRODUCTION

Product lifetime extension – not instead of but in addition to materials recycling – and the ability to create, deliver and capture economic value from long or extended product lifetimes are essential to a circular economy.

1.1 INTRODUCTION

This thesis is about the development of a design methodology that can help industrial designers to design products with a long or extended lifetime in support of a circular economy. The research is presented from an industrial design perspective.

The aim of a circular economy is to limit the flows of materials and energy into and out of the economic system at levels that in principle can be tolerated and sustained indefinitely by nature whilst protecting the capacity of the economic system to create wealth (Korhonen, Honkasalo & Seppälä, 2018). In a circular economy, the economic and environmental value of materials is preserved by keeping them in the economic system for as long as possible, preferably by lengthening the useful lifetimes of products formed from them and, when lifetime extension at product level is no longer possible for environmental or economic reasons, by looping products back into the manufacturing process so their constituent materials can be reused. The notion of *waste* no longer exists in a circular economy because products and materials are, in principle, reused and cycled indefinitely. It follows that product lifetime extension – not instead of but in addition to materials recycling – and the ability to create, deliver and capture economic value from long or extended product lifetimes are essential to a circular economy. Industrial design has the potential to contribute significantly to achieving the goals of a circular economy (SER, 2016; EC, 2015a; EPEA, 2004) because the design of a product directly affects the characteristics of the physical product as well as the structure of the entire value chain (De los Rios & Charnley, 2016). The thesis belongs to the discipline of design research (Faste & Faste, 2012):

> [Design research] includes the study of how designers work and think, the establishment of appropriate structurers for the design process, the development and application of new design methods, techniques and procedures, and the reflection on the nature and extent of design knowledge and its application to design problems (Cross, 1984 as cited in Kuijer, 2014, p. 1).

Within this larger discipline, the thesis focuses on the domain of sustainable design, i.e., that segment of industrial design that in the creation of products and systems intentionally takes on the additional responsibility of *"balancing economic, environmental and social aspects"* (Charter & Tischner, 2001, p. 121) with the end goal of fostering and safeguarding lasting human well-being.

The field of sustainable design originated in eco-design (Wever & Vogtländer, 2015). Eco-design is the systematic integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle (EC, 2009a, Tischner, Schminke, Rubik & Prösler, 2000). As the field of sustainable design evolved, its scope gradually enlarged. Where eco-design is primarily concerned with resource flows, sustainable design has also come to include aspects such as social sustainability, for instance. As the thesis takes a material flows perspective on the circular economy, it will compare product design for a circular economy with eco-design (but not with sustainable product design).

Over the past six decades, the field of eco-design has framed product lifetime extension mainly from a resource efficiency perspective (De Pauw, 2015; Bjørn & Hauschild, 2012), largely ignoring the business implications ushered in by the circular economy concept. The development of design methodologies in the field of sustainable design (Pigosso, McAloone & Rozenfeld, 2015, Bovea & Pérez-Belis, 2012, Luttropp & Lagerstedt, 2006), including those aimed at product lifetime extension, has focused on interventions for improving the design of tangible products in order to reduce the environmental impact generated by these products over their entire lifecycle (De Pauw, 2015; Bjørn & Hauschild, 2012; Stevels, 2007). Notwithstanding its usefulness for reducing the environmental impact of products (De Pauw, 2015), the eco-design approach has left largely unexplored the interaction between (the design of) long-life tangible products and their business-economic context. As a consequence of this rather narrow way of framing product lifetime extension – i.e., focused on tangible products and resource efficiency – limited attention has been given to the development of a design methodology explicitly aimed at leveraging the interactions between (the design of) physical products and their business-economic context to systematically increase, let alone optimize, product lifetimes.

With the recent increase in attention paid to the circular economy concept (Korhonen et al., 2018; Geisendorf & Pietrulla, 2017) and its adoption by the EU (Korhonen et al., 2018; Geisendorf & Pietrulla, 2017; EC, 2015b), the resulting knowledge gap has gained significance and needs to be addressed, as the economic and environmental success of the circular economy concept hinges on its ability to leverage the above interactions.

This thesis sets out to develop a design methodology with the intention to help fill this knowledge gap. Daalhuizen (2014) defined a design method as *"a description of a design activity which has been rationalized and abstracted from observations or imagined based upon theory with the purpose of helping designers to see the structure of that activity (so that they can learn or teach it, extend their capabilities, communicate it or reflect on their own or other's* [*sic*] *actions"* (p. 34). As a circular economy is not (yet) a reality, the development of design methods in this thesis will be of the above "imagined based on theory" variety.

To create new knowledge in the form of a design methodology (Faste & Faste, 2012) on how the interaction between (the design of) products with a long or extended product lifetime and their specific business-economic context can be leveraged to systematically increase product lifetimes, the thesis will begin in chapters 2 and 3 by reviewing the literature from the domains of sustainability and eco-design to identify and develop a comprehensive terminology and a coherent set of guiding principles and design strategies for product design for a circular economy. It will then in chapter 4 venture into the literature from the business sciences to explore the relationship between business models and long and extended product lifetimes, resulting in a typology of circular business model types able to create, deliver and capture value from long or extended product lifetimes in a circular economy.

Next, the thesis will in chapter 5 take inventory of potential barriers to creating, delivering and capturing value from long or extended product lifetimes in a circular economy and existing approaches to surmounting these barriers by means of a further review of the literature and seven company interviews. Based on the results from the literature review and the findings from these company interviews, the thesis will then in chapter 5 propose a new business management and design approach, i.e., managing obsolescence to help these circular business models for long and extended product lifetimes achieve their environmental and economic goals. Lastly, the thesis will in chapter 6 present a new design methodology for managing obsolescence. This new methodology is intended to support and provide guidance to industrial designers when designing long-life products in support of (a transition to) a circular economy. It provides new design methods and typologies in support of managing obsolescence, insight into how and when to best apply these methods and insight into where and in collaboration with whom to apply these methods in the product innovation process.

Conclusions and recommendations for further research will be presented in chapter 7.

1.2 INDUSTRIAL DESIGN, SUSTAINABLE DESIGN, CIRCULAR ECONOMY AND PRODUCT LIFETIME EXTENSION

The literature offers many different definitions for and descriptions of the concept of industrial design (e.g., IDSA, 2017; Van Boeijen, Daalhuizen, Zijlstra & Van der Schoor, 2013; Roozenburg & Eekels, 1995; Heskett, 1987). Historically, the addition of the adjective "industrial" to the concept of design served to highlight the separation of the act of designing a product from the act of making the actual tangible product that sets industrial design apart from *"traditional crafts"* (Heskett, 1987, p. 10) and makes it suitable for use in an industrial context (Heskett, 1987). Since its introduction over half a century ago, however, the meaning of the term "industrial design" has expanded from its more narrow, tangible product-based interpretation (e.g., Heskett, 1987) to also incorporate the conception and development of systems, services and experiences that include, support or surround tangible products, as can be seen from the following extended definition of industrial design proposed by the World Design Organization (2017), which is adopted by the thesis:

> Industrial Design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences. Industrial Design bridges the gap between what is and what's possible. It is a transdisciplinary profession that harnesses creativity to resolve problems and co-create solutions with the intent of making a product, system, service, experience or a business, better. At its heart, Industrial Design provides a more optimistic way of looking at the future by reframing problems as opportunities. It links innovation, technology, research, business, and customers to provide new value and competitive advantage across economic, social, and environmental spheres.

In most companies built around tangible products, the process of designing the actual tangible product is but one part of a larger, ongoing, product innovation process (Van Boeijen et al., 2013; Buijs, 2012; Roozenburg & Eekels, 1995) (See also Appendix A: The Product Innovation Process). This larger product innovation process loops back onto itself in a continuously repeating sequence of steps, i.e., *"product use, strategy formulation, design brief formulation, product development and market introduction"* (Van Boeijen et al., 2013, p. 23), whereby product use is often taken as the beginning of the continuously repeating sequence to stress that new products are always conceived, designed, developed and introduced in the context of - and often in response to the shortcomings or success of - existing products. Because larger organisations typically have more than one product in their product portfolio at any given time, their larger product innovation process often involves (strategic) planning for, and managing the development of, multiple products (e.g., products with a different function or products intended for different markets and customer segments) in parallel: *"a product mix"*

(Van Boeijen et al., 2013, p.21). However, in order to not let the complexity from developing multiple products cloud the core of the argument presented in the thesis, the remainder of the thesis will consider the product innovation process for a single new product. The business function of industrial design is guided by overall business objectives and does not set its own design goals, nor is it completely free in deciding how to achieve them: In our highly competitive markets, the specifications for the functionality and styling of new products, as well as the timing of their introductions and the extent to which technical information and spare parts will be made available have all become strategic business decisions (Freedman, 2013; Rainey, 2005; Roozenburg & Eekels, 1995; Mayo, 1993; Porter, 1980).

At present, the role of most industrial designers is limited to generating and proposing design solutions in the form of concepts and designs for tangible products that support the strategic objectives of a company that have already been set out in conjunction with, or are often determined by, the capabilities, limitations and plans of other functions within the larger company, such as production and marketing.

More elaborate discussions of the product innovation process, strategy (development) and (the roles of) marketing can be found in Appendix A: The Product Innovation Process, Appendix C: The Strategy Concept: Definition, Evolution and Ontology and Appendix D: The Marketing Concept: Definition, Evolution and Roles.

As part of the domain of sustainable product design, the discipline of eco-design is well developed and recognized. It provides product designers with a design methodology, i.e., a range of guiding principles, eco-design strategies, and methods, for systematically integrating environmental aspects into product design with the aim to improve the environmental performance of the product throughout its whole life cycle (Pigosso et al., 2015; Bovea & Pérez-Belis, 2012; EC, 2009a; Luttropp & Lagerstedt, 2006; Tischner et al., 2000; Brezet & Van Hemel, 1997).

The thesis argues, however, that there is a fundamental distinction to be made between eco-design and product design for a circular economy, i.e., circular product design, and that this means that circular product design requires a new, or at least an adapted, design methodology.

Relative vs. Absolute Perspective on Sustainability

The most important difference between eco-design and circular product design is of a methodological nature. The current design methodology (i.e., guiding principles, strategies, and methods) for product lifetime extension as proposed by eco-design is rooted in the here and now (which is the linear economy). One important guiding principle in eco-design is the European waste hierarchy (EC, 2009b), which assumes that all products at a certain time inevitably will become waste. Eco-design is what Faber, Jorna & Van Engelen (2005) and De Pauw (2015) refer to as a *relative* approach. It *"starts with the present state of affairs and identifies existing problems, which people subsequently attempt to solve. Improvements take place incrementally ... In contrast to the absolute approach, the focus of this relative approach is not the good, but the less worse or better"* (Faber et al. 2005, p. 8). It is precisely this focus on existing problems that was critiqued (e.g., De Pauw 2015), because how can designers come up with truly sustainable or circular innovations if the current methods only lead them to optimize what is already there? This led design thinkers such as McDonough and Braungart (2002), Benyus (1997), and Webster (2015) to propose more absolute approaches. In contrast to relative approaches, absolute approaches to sustainability (Faber et al., 2005) start with *"an idealised end state"* (Faber et al., 2005, p. 3) or "the good" instead of "the less worse or better" (De Pauw, 2015; Faber et al., 2005). Systematically working back and forth to close the gap between there and here, absolute approaches to sustainability aim to mimic a closed loop, type III ecology (Graedel & Allenby, 2003; Lifset & Graedel, 2002) (see figure 1.2.1) as closely as possible. In such a cyclic, type III ecology, *"resources and waste are undefined, because waste to one component of the eco-system represents resources to another"* (Graedel & Allenby, 2003, p. 50). With its end-goal of realizing an envisioned future socio-economic system that is inherently sustainable (De Pauw, 2015) and its dismissal of the concept of waste, the thesis considers the circular economy concept to be such an *absolute* approach to sustainability.

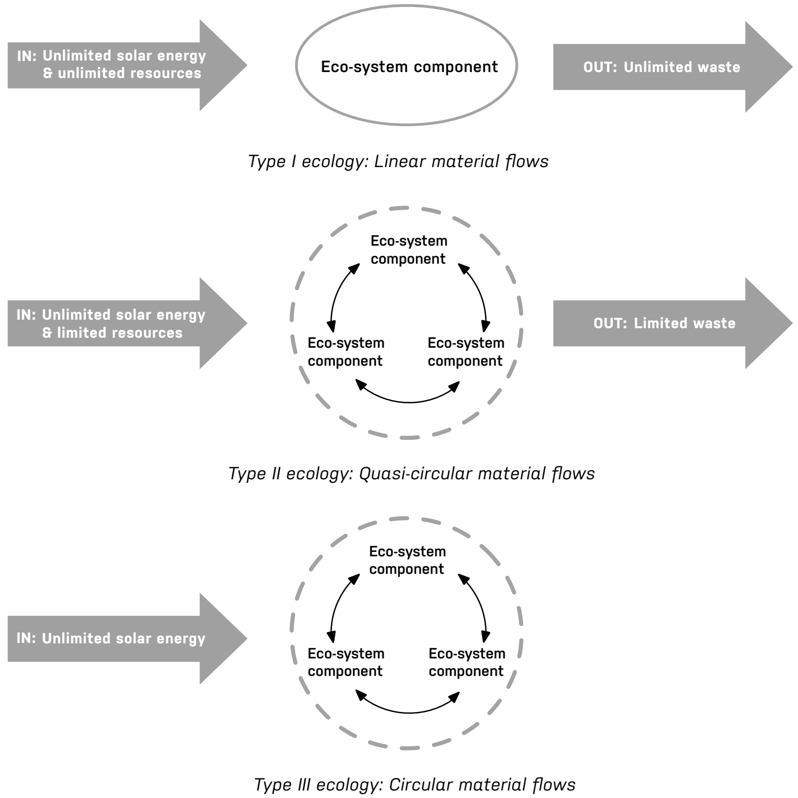


Figure 1.2.1: Ecosystems vary according to the circularity of their resource flows, ranging from a type I ecology that is the least circular and most reliant on external resources and sinks, to a type III ecology that has the greatest degree of circularity and least reliance on external resources and sinks (Lifset & Graedel, 2002). Adapted from Lifset and Graedel, 2002 and Graedel and Allenby, 2003.

So far, absolute approaches have been viewed by many as utopian, impractical, and unnecessarily normative. Some researchers have argued that the end result of both types of approaches in practice will largely be the same, as *"an envisioned ideal may need to be watered down to make it achievable in the short run"* (Wever & Vogtländer, 2015, p. 517). This however does not necessarily have to be so. Absolute approaches to sustainability, not being constrained to solving problems in the limited context of the here and now, could prove advantageous over and complementary to relative approaches to sustainability for two reasons. The first is that because absolute approaches imply notions of an ideal state (i.e., the circular economy as an ideal state), they can challenge industrial designers to strive for such an ideal state, thus opening up a wider solution space and an increased likelihood of finding innovative solutions (De Pauw, 2015). This could lead to new solutions that may not be evident or considered viable when the problem is viewed from a relative, in this instance linear economy, perspective (Maxwell & Van der Vorst, 2002; De Pauw, 2015), but which emerge only when the problem is allowed to be considered in a different (socio-economic) context. The second reason is that, because of its widened perspective, an absolute approach can help industrial designers avoid what Ehrenfeld (2008) and Braungart, McDonough and Bollinger (2007) saw as one of the dangers inherent to a relative approach to sustainability, namely that interventions aimed at increasing eco-efficiency might unintentionally *"have adverse effects if the underlying problems are not addressed"* (De Pauw, 2015).

Reducing Environmental Impact vs. Preserving Added Economic Value

The second ground for distinction flows from the fundamental methodological difference mentioned above. Eco-design and the circular economy concept can both be traced back to industrial ecology and environmental management. In theory, they have by and large the same goals, i.e., *"dematerialization"* (Heiskanen, 1996, p. 2) and "*detoxification"* (Heiskanen, 1996, p. 2), and use similar approaches. In practice, however, eco-design and circular product design differ as a result of the relative emphasis they put on the different approaches to achieve those goals, e.g., through *"resource efficiency"* (Heiskanen, 1996, p. 2) or *"narrowing"* (Bocken, De Pauw, Bakker & Van der Grinten, 2016, p. 309) resource flows, *"product life extension"* (Heiskanen, 1996, p. 2) or "*slowing"* (Bocken et al., 2016, p. 309) resource flows and *"product recyclability"* (Heiskanen, 1996, p. 2) or *"closing"* (Bocken et al., 2016, p. 309) resource flows or creating *"resource loops"* (Bocken et al., 2016, p. 309). This is most visible in those instances where these particular approaches work against each other. For example, making a product lighter to reduce resource consumption may decrease its durability if taken too far (Heiskanen, 1996). As a relative approach to sustainability, eco-design is focused on reducing the environmental impact across a single product life cycle, whereas the circular economy concept and circular product design by virtue of their absolute end-goal of no waste must focus on preserving added economic value during and across multiple product use cycles, i.e., keeping products and materials in the economic system for as long as possible, hence their emphasis on product lifetime extension. In the above light weighting example, eco-design would opt for interventions promoting resource efficiency and materials recycling. Product design for a circular economy would put more emphasis on interventions for slowing resource flows through lifetime extension at product level, such as product reuse, maintenance, upgrading, repair, refurbishment and remanufacturing (WRAP, 2017; EMF, 2015; 2014; 2013; 2012).

Limited Consideration of Business-Economic Context

The third difference between eco-design and circular product design pertains to the extent to which they take the business-economic context of products into consideration. From the perspective of a relative approach to sustainability like eco-design, companies can decide to limit interventions for reducing the environmental impact once they become too costly and can decide to expel materials that cannot profitably be recycled from the economic system as waste. This has allowed eco-design to work within the boundaries of conventional business models based on transfer of product ownership and largely ignore business-economic implications beyond that of cost. In an absolute approach to sustainability, such as the one taken in the circular economy concept, however, companies must strive to limit the environmental impact of their products to a level that can be tolerated and sustained indefinitely by nature. They are no longer allowed to expel materials that cannot profitably be recycled as waste and must keep products and materials in the economic system for as long as possible. In order to protect their capacity to generate wealth in the face of these environmental requirements, these companies (and thus circular product design) must focus on preserving added economic value, i.e., extending product lifetimes. However, because most purchases in saturated markets (as most of our markets for products currently are (Bayus, 1991)) are replacement purchases, long and extended product lifetimes do not go well with the transfer of product ownership-based business model types that are currently prevalent in companies built around products (Malone et al., 2006)). Contrary to eco-design, circular product design must therefore challenge these conventional, transfer of product ownership based, business model types and take into account (changes to) the wider business-economic context, such as the introduction of alternative business model types (e.g., Antikainen, Lammi, Paloheimo, Rüppel, & Valkokari (2015)) for the products to be designed.

Product lifetime extension is widely considered one of the most promising options for effectively reducing the rate at which our economy uses up natural resources and produces waste (e.g., Den Hollander et al., 2017; SER, 2016; EMF, 2015, 2014; 2013; Tukker, 2015; Stahel, 2010; Cooper, 2010; Vezzoli & Manzini, 2008; Heiskanen, 1996), provided it is applied sensibly and selectively as *"extended product lifetime is not per definition an environmental improvement"* (Van Nes & Cramer, 2005, p. 287). It is recognized in the literature (e.g., Bakker, Wang, Huisman & Den Hollander, 2014; Burns, 2010; Van Nes & Cramer, 2005) that it sometimes is preferable to shorten the lifetime of a product. Some academics (e.g., Charter & Tischner, 2001; Tischner et al., 2000; Van Hemel, 1998) therefore prefer to speak of product *"lifetime optimisation"* (Van Nes & Cramer, 2005, p. 287), maximizing a product's *"utilization time"* (Sirkin & Ten Houten, 1994, p. 229), or of striving for *"appropriate longevity"* (Burns, 2010, p. 51) of a product instead, referring to the process of altering (i.e., either shortening or lengthening) the lifetime of a product to minimize or reduce its environmental impact over its life cycle. In most instances, however, with the notable exception of cases where an existing product is significantly less energy efficient than a newer, replacement product, extending the lifetime of a product is the desired option from an environmental point of view (Van Nes & Cramer, 2005).

1.3 Research Gap, Aim, Questions, Approach and Scope

1.3.1 Research Gap

With the growing interest in the circular economy (Korhonen et al., 2018; Bressanelli, Peronoa & Saccani, 2017; Linder & Williander, 2017; Prendeville & Bocken, 2017; Geissdoerfer, Savaget, Bocken & Hultink, 2016; Lewandowski, 2016; Rizos et al., 2016), product lifetime extension (and its potential implications for industrial designers and industry) have been put firmly back on the agenda: *"CE highlights the importance of high value and high quality material cycles in a new manner"* (Korhonen et al., 2018, p. 45).

The thesis argues that the field of eco-design has not explored product lifetime extension in sufficient detail (see section 1.2). In spite of the sizeable body of literature in support of the potential environmental and economic benefits of extended product lifetimes and the increasing recognition of the role of business models as vehicles for promoting environmental and social sustainability (Bocken, Short, Rana & Evans, 2014; Boons & Lüdeke-Freund, 2013), the literature (both scientific and grey) that focuses on the industrial design implications of business model types for extended product lifetimes in a circular economy is sparse (e.g. Den Hollander et al., 2017; Bocken et al., 2016; Bakker, Den Hollander, Van Hinte & Zijlstra, 2014). The effect of the business-economic context of products on their lifetime, for example, has repeatedly been reported in both the business and sustainability-oriented literature (e.g., Reim, Parida & Örtqvist, 2015; Tukker, 2015; Tukker & Tischner, 2006; Tukker, 2004; Mont, Dalhammer & Jacobsson, 2006; Mont, 2004, 2002; Swan, 1970; Levhari & Srinivaran, 1969). Research on extending product lifetimes within eco-design, however, has so far mainly been focused on developing strategies and approaches for safeguarding the technical functionality of tangible products over time, for example prevention engineering (Stahel, 1994), design for repair, design for maintenance and design for upgradability (Van Nes, 2003), and for enabling products to, at least in theory, evoke a lasting emotional response from their individual users, for example design for emotional durability (Chapman, 2009), design for product attachment (Mugge, 2007) or design for mindfulness (Grosse-Hering, Mason, Aliakseyeu, Bakker & Desmet, 2013).

In the literature of the business sciences, research into business model types for extended product lifetime is almost non-existent. Existing research on product lifetime and product lifetime extension has so far mainly focused on operational, e.g., process and management, aspects relating to different modes of product life extension and closed-loop supply chains (e.g., Govindan, Soleimani & Kannan, 2014; Guide Jr. & Van Wassenhove, 2009; Linton & Jayaraman, 2005; Guide Jr., Harrison & Van Wassenhove, 2003). Other business sciences research into product lifetime extension is concerned mainly with reducing costs and risks associated with product lifetime in business-to-business processes like reducing downtime, for example in manufacturing, or with the mitigation of operational risks and/or reduction of operational cost in obsolescence-sensitive industries such as aviation and defence (e.g., Zheng, Terpenny & Sandborn, 2016; Bartels, Ermel, Sandborn & Pecht, 2012; Rojo, Roy & Shebab, 2010).

As a result of this limited attention paid to, and the narrow and relative perspective on, product lifetime extension in the fields of sustainable design and the business sciences, there currently are three problems from a research perspective with regard to design for product lifetime extension in a circular economy. First, the current literature uses ambiguous and confusing terminology with regard to product end-of-life (Gharfalkar, Ali & Hillier, 2016; Butti, 2012) and interventions for product lifetime extension (Gharfalkar et al., 2016; Oakdene Hollins Ltd., 2007). Secondly, the current literature lacks information on the relationships between strategies for product design for a circular economy and business-economic context when designing for product lifetime extension in a circular economy. Thirdly, there is a lack of guiding principles, strategies and methods to help industrial designers implement design for product lifetime extension in a circular economy.

1.3.2 Research Aim, Questions and Approach

Nobody knows what the real form of a truly circular economy is and whether or not it could work. Nevertheless, designers should be expected to explore new avenues and promising directions. The urgency of this was expressed by the CEO of design consultancy IDEO, Tim Brown (Brown & Katz, 2011): *"It is hard to imagine a time when the challenges we faced so vastly exceeded the creative resources we have brought to bear on them"* (p. 3). To meet these challenges, however, industrial designers need an up-to-date set of principles, strategies, and methods to guide the conceptualization and embodiment of their designs.

Therefore, the aim of this thesis is to identify guiding principles, design strategies and design methods that could underpin product design for the circular economy from an absolute perspective, taking as a starting point the notion that eco-design (i.e., a relative approach to sustainability) and circular product design (i.e., an absolute approach to sustainability) differ on a fundamental level. The thesis asks the question: If we accept the *absolute* idea of a circular economy as described earlier (i.e., a circular economy as an ideal end-state (Faber et al., 2005) that mimics a cyclic, type III ecology (Graedel & Allenby, 2003; Lifset & Graedel, 2002) as closely as possible), how would this affect the way we design products in a circular economy and what design methodology could industrial designers use to help them design products for a circular economy?

The main research question of the thesis is:
"What design methodology can help industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?"

The above question seeks to identify guiding principles, strategies and methods for a suitable design methodology, and adds the fit with specific business model types to reflect that industrial design is guided by business strategy and objectives (Van Boeijen et al., 2013; Adamson, 2003; Heiskanen, 1996; Roozenburg & Eekels, 1995)
To be able to provide an answer to the main research question of the thesis, a number of sub-research questions have been formulated that will need to be answered first:

A: "How can product lifetime extension in a circular economy be defined within the context of industrial design?"

Question A addresses the problem of the ambiguous and confusing terminology in the current literature with regard to product end-of-life (Gharfalkar et al., 2016; Butti, 2012) and interventions for product lifetime extension (Gharfalkar et al., 2016; Oakdene Hollins Ltd., 2007). The aim of question A is to establish comprehensive and unambiguous terminology for product end-of-life states and interventions for product lifetime extension, in terms that are intended for use by industrial designers, including an overview of possible design approaches to product lifetime extension at an abstract level, which can provide a basis for the development of guiding principles, design strategies and methods that could underpin circular product design.

B: "What guiding principles and design interventions can industrial designers use when designing for long and extended product lifetimes in a circular economy?"

Question B goes deeper into how industrial designers can best support the abstract design approaches to product lifetime extension resulting from question A with actual design interventions at the level of the tangible product. The aim of question B is to arrive at an overview of the options available to industrial designers and gain insight into the factors affecting and guiding how industrial designers make a selection from these options.

C: "What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?"
Question C is intended to establish the different business contexts that industrial designers can expect to encounter and design for in a circular economy. The business model type that is currently most used by companies producing tangible products (Malone et al., 2006) thrives on replacement purchases. As in saturated markets (as most of our Western markets currently are (Bayus, 1991)) the frequency of replacement purchases tends to increase with shortened product lifetimes and decrease with extended product lifetimes; it follows that business models based on that particular type do not work well with extended product lifetimes and are therefore of little use in a circular economy. The aim of question C is to identify those business model types that can create, deliver and capture value from extended product lifetimes, as their particular business strategies and objectives will provide the business context for the work of industrial designers in a circular economy.

D: "What guiding principles and management strategies can businesses use when creating, delivering and capturing value from long and extended product lifetimes in a circular economy?"

Question D goes deeper into the specific economic and environmental business goals, objectives and barriers of business models that can capture, deliver and create value from long and extended product lifetimes. The aim of question D is to identify guiding principles and management strategies that can be used by these business model types to achieve those goals and surmount those barriers, as these are the principles and strategies that industrial designers would need to support with their design interventions.

E: "To what extent can some combinations of design interventions and business model types be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?"

With the business context for circular product design and the spectrum of design interventions now established by the answers to questions A, B, C and D, the question that remains for industrial designers is which design intervention(s) to best apply when designing for a particular business model type. The aim of question E is to determine whether some combinations of design interventions and business model types are more likely to be successful than others and, if so, to identify the factors that are responsible for these differences.

1.3.3 Scope
The question of whether product lifetimes should or should not be extended from an environmental point of view is out of the scope of this thesis. The body of literature relevant to this question in the field of Sustainable Product Design is vast (e.g., Bakker & Schuit, 2017; Pérez-Belis, Bakker, Juan & Bovea, 2017; Prakash, Dehoust, Gsell, Schleicher & Stamminger, 2016; Bakker, Wang et al., 2014; Tasaki, Motoshita, Uchida & Suzuki, 2013; Yu et al., 2010; Kiatkittipong, Wongsuchoto, Meevasane & Pavasant, 2008; Kim, Keoleian & Yuhta, 2006). As of yet, however, the literature does not provide a simple answer (Bakker & Schuit, 2017). What it does make clear, however, is that answering the question is extremely complex and depends on the parameters of the particular scenario that is considered, for example product type (e.g., energy consuming or not), type of use and user (e.g., frequent or occasional use), method of measurement, geographical location and local infrastructure. The thesis works from the premise that creating economic value through extended product lifetime leads to a net reduction in environmental impact when the total environmental impact, associated with providing a certain perceived use value (Bowman & Ambrosini, 2000) over a certain period time, is lower for a single product with an extended product lifetime than it is for a product and one or more replacement products. Total environmental impact in this instance includes the environmental impact resulting from manufacture, use and interventions for product lifetime extension (Heiskanen, 1996). The concept of perceived use value is employed as the basis for comparison between products instead of the more commonly used functionality, as it reflects that product lifetime is defined in this thesis in terms of obsolescence, e.g., loss of perceived use value, instead of mere loss of function. Furthermore, while aware of its potential limitations (Korhonen et al., 2018), this thesis assumes that an absolute circular economy contributes to global net sustainability.

As mentioned in section 1.2, industrial design is driven by business objectives (e.g., Van Boeijen et al., 2013; Adamson, 2003; Roozenburg & Eekels, 1995). With regard to business objectives, the thesis adopts the literature-based premise that the purpose of any for-profit business is to make a profit (Tukker, Van den Berg & Tischner, 2006; Heiskanen, 1996) whilst at the same time serving the long-term interests of the company (Tukker et al., 2006) and its stakeholders (Stout, 2017).

The form of business ownership, e.g., whether a business is privately owned or publicly listed, often also has an influence on product lifetime, as private and public shareholder demands can differ. Privately owned companies can autonomously and for reasons of their own choose to make it their strategy to manufacture and market high grade, high quality products with a long product lifetime potential, and accept the financial consequences of their decision with no responsibilities to holders of publicly listed shares. For publicly listed companies, matters are different. Many investors in publicly traded shares are first and foremost interested in the highest, and preferably short term, return on their investment (Graham, 2006). This can limit the options available to the management of such businesses and affect their decisions with regard to sustainability issues, such as product longevity (e.g., Financial Times, 2017). Although the effect of business ownership on product lifetime decisions is acknowledged, it will not be pursued further here as the thesis adopts an absolute perspective on a circular economy and takes the presence of a business interest in product longevity as a starting point. Swan (1970) and others, e.g., Levhari & Srinivaran (1969), also have recognized the effects of market structure (e.g., pure competition, monopolistic competition, oligopoly or pure monopoly) on product lifetime decisions. Changing the structure of a market, however, is generally beyond the power of single businesses and industrial designers. The topic is therefore also considered to fall outside the scope of this thesis and will not be explored further here.

Lastly, the focus of the thesis is limited to the interaction of design strategies and business model types that concern durable consumer products, i.e., *"tangible* [consumer] *goods that normally survive many uses"* (Kotler, 1984, p. 465) and that may or may not be accompanied by intangible services. This is in line with Heiskanen (1996) who in "Conditions for product lifetime extension" stated that *"non-durables"* (p. 9), or "consumables", i.e., tangible single-use consumer goods such as foods, packaging or toilet paper (Heiskanen, 1996; Kotler, 1984), are *"mostly not relevant for PLE* [Product Lifetime Extension]*"* as they have their *"chief* [environmental] *impacts at* [the] *production/disposal stage"* (Heiskanen, 1996, p. 9).

Knowledge about the potential effects of the interactions mentioned above can be used throughout the entire product development process, from formulating goals and strategies to realization. Although they may apply and prove useful in select instances, the terminology and typologies for interventions for product lifetime extension and business models for extended product lifetimes, as well as the design approaches, design strategies and framework for product lifetime extension presented in the thesis are not intended to be applied to consumables.

1.4 RESEARCH POSITIONING, SCIENTIFIC RELEVANCE AND SOCIETAL RELEVANCE

1.4.1 Research Positioning and Scientific Relevance

The newness and scientific relevance of the research reside in that the thesis explores (design for) product lifetime extension in a circular economy from an *absolute* perspective on sustainability (De Pauw, 2015; Faber et al., 2005). This has not been done before as the sustainable design field has in the past almost exclusively looked at (design for) product lifetime extension from a *relative* perspective on sustainability (De Pauw, 2015; Faber et al., 2005). By defining product lifetime in terms of obsolescence instead of in terms of (loss of) functionality, the research furthermore highlights both the need for and the option of addressing subjective and intangible factors in coordinated conjunction with objective or engineering factors when designing for long and extended product lifetimes in a circular economy in order to (re)create and deliver lasting perceived use value. The (results from) the seven company interviews add to the extant literature by providing new insights into how factors other than the tangible product affect the manufacture and marketing of products intended to have a long or extended product lifetime. As such, the research presented in the thesis informs the discussion on the role of industrial designers in a circular economy and contributes to the body of scientific knowledge on industrial product design for a circular economy. By presenting a new terminology for product design for product lifetime extension in a circular economy and new typologies for interventions, design strategies and circular business models for preserving product integrity, the research additionally helps further design research into design for the circular economy and provides both industrial design students and practitioners with an expanded and more precise vocabulary for entering into (discussions concerning) the field of industrial product design for a circular economy.

The research contributes to (sustainable) design methodology by proposing a new methodology, i.e., design for managing obsolescence, consisting of a set of new methods that can support industrial design education and practice. In a wider context, the research also contributes to a much-needed (Korhonen et al., 2018; Bocken et al., 2014) deeper understanding of the circular economy as an absolute concept and of its potential and limitations.

A consequence of the thesis taking an absolute perspective to the circular economy concept and (design for) product lifetime extension is that a normative, prescriptive component is introduced to – and underlies all of – the work.

1.4.2 Societal Relevance

The need for effective and scalable solutions that can help to bring down the rates at which our economy uses up natural resources and produces waste to sustainable levels has at present become perhaps more pressing than ever before (Geissdoerfer et al., 2016; Markard, Raven & Truffer, 2012; Seiffert & Loch, 2005; WBCSD, 2010; Meadows, Randers & Meadows, 2004). Since the beginning of the Industrial Revolution, the rates at which we use up natural resources and produce waste through the production and consumption of products have increased exponentially (Bressanelli et al., 2017) to the extent that they have now become critical from an environmental (e.g., depletion and pollution) and economic (e.g., supply) point of view (Graedel, Harper, Nassar & Reck, 2015; Huisman et al., 2012; Köhler, 2012; Allwood, Ashby, Gutowski, Worrell, 2011; McKinsey Global Institute, 2011; UNEP, 2010). The current literature provides no indications that this pace will relent or decline in the foreseeable future (Krausmann et al., 2009). Rather, it contains indications that the pace will most likely increase. On a global level, the literature on resource consumption for example shows some evidence of relative decoupling over the past decades but – as a result of continuing economic growth – virtually none of absolute decoupling (Jackson, 2009). When these trends are extrapolated, they indicate ongoing net growth in resource consumption (Jackson, 2009). This is in line with Hoornweg & Bhada-Tata (2012) who predicted that the amount of waste that is generated globally on a daily basis will double by 2025 (as compared to 2012 levels) to a staggering total of 6.5 million tons.

The research presented in the thesis is timely and has societal relevance because the European Commission has in recent years adopted the circular economy concept as a promising solution (Geisendorf & Pietrulla, 2017; Korhonen et al., 2018; EC, 2015b) for promoting sustainability and solving, or at least mitigating, future problems caused by increasing resource use and waste production. In 2015, the European Commission presented its Circular Economy Package – including Closing the Loop, an EU action plan for the circular economy (EC, 2015b, 2017a) – to facilitate and speed up the transition to a circular economy. In 2017, the European Parliament underlined the importance of (design for) long and extended product lifetimes to a circular economy by adopting resolution 2016/2272(INI), A longer lifetime for products: benefits for consumers and companies (EC, 2017b). The provisional text of this resolution explicitly calls for *"designing robust, durable and high-quality products"* (EC, 2017b, p. 5), *"promoting repairability and longevity"* (EC, 2017b, p. 6), "*operating a usage-oriented economic model"* (EC, 2017b, p. 7) and *"measures on planned obsolescence"* (EC, 2017b, p. 9). These topics are at the heart of the research presented in this thesis, which, for the first time in the literature, explores the implications of absolute decoupling from an industrial design perspective in the context of a circular economy. In addition to contributing to a deeper understanding of the role of the industrial designer in a circular economy and of the circular economy as an absolute concept, the thesis translates these findings into a new design methodology that is intended to help practicing industrial designers (and businesses) make design decisions that will facilitate and support the transition from a linear economy and its problems, as sketched out above, to a circular economy, in line with the goals set by the European Commission.

1.5 RESEARCH DESIGN

The research in the thesis makes use of both theoretical and empirical data.

Gathering and Processing Theoretical Data

As far as the theoretical data is concerned, the thesis uses literature review as a research methodology in its own right in order to develop a vocabulary to address product lifetime extension from an industrial design and business perspective and to develop classifications (i.e., typologies) that subsequently can be used as a basis for the development of design methodology. This use of literature review differs from how literature review is more commonly used in preparation for, and contextualization of, subsequent empirical research: When literature review is used in conjunction with empirical research, the data for the empirical research is gathered from a sample taken from a population of people or objects. When literature review is employed as a methodology in its own right, however, the actual research data to be analysed is obtained from sampling the literature itself (Comerasamy, 2017).

Literature reviews can be performed in a number of different ways, ranging from what Hagen-Zanker & Mallet (2013) termed *"orthodox literature reviews"* (p. 3) to *"systematic* [literature] *reviews"* (p. 1), each with their own advantages and drawbacks (Hagen-Zanker & Mallet, 2013)

As the research presented in this thesis is explorative and needs to look for – and even depends on – connections across disciplinary boundaries, the ability to capture additional, potentially relevant information, knowledge and context by being allowed to cast a wide net is essential. For this reason, the thesis follows a variety of the systematic review approach that *"adheres to the core principles of 'full' systematic reviews but allows for greater flexibility and reflexivity in the process"* (Hagen-Zanker and Mallet, 2013, p. 5). The aim of the alternative approach as developed by Hagen-Zanker and Mallet (2013) is to mitigate some of the disadvantages of conventional systematic literature reviews whilst maintaining most of their advantages over orthodox reviews.

The process for an alternative systematic literature review as proposed by Hagen-Zanker & Mallet (2013) consists of eight main stages as pictured in figure 1.5.1. The differences between this methodology and the more conventional systematic literature review are explained in more detail below.

As can be seen from figure 1.5.1, the stages making up the alternative systematic literature review are largely in line with those of a conventional systemic literature review. The difference between the two methodologies resides in stage 5, retrieval. Instead of limiting the retrieval stage to search results based on strictly specified search strings and an exclusive focus on academic literature (e.g., *"Track I: Academic literature search"* (Hagen-Zanker and Mallet, 2013, p. 10) in figure 1.5.1), the alternative methodology allows for two additional tracks. The first of these is what is known in the literature as snowballing (e.g., *"Track II: Snowballing"* (Hagen-Zanker and Mallet, 2013, p. 10) in figure 1.5.1).

The process of snowballing allows for taking on board and examining relevant publications that did not necessarily surface in track I, based on the experience and advice of experts in the field, and also allows for working backward and forward from the references in those publications. Although this approach does introduce a degree of subjectivity into the research, due to the selection of both the experts and the publications, it also is *"extremely useful to get a sense of which literature has been important and influential in the field – which may not necessarily be the high-quality peer-reviewed journal articles"* (Hagen-Zanker and Mallet, 2013, p. 10). The second additional track (e.g., *"Track III: Grey literature capture"* (Hagen-Zanker and Mallet, 2013, p. 10) in figure 1.5.1) is intended to capture relevant materials that are located outside the realm of scientific literature, such as books, working papers or reports from industry, policy makers or other institutions. It may be evident that allowing these additional tracks to enter the systematic literature review process will sacrifice some of the rigour and objectivity associated with conventional systematic literature reviews. However, allowing them in can also help to *"increase the breadth, relevance, topicality and ultimate utility"* (Hagen-Zanker & Mallet, 2013, p. 11) of the review.

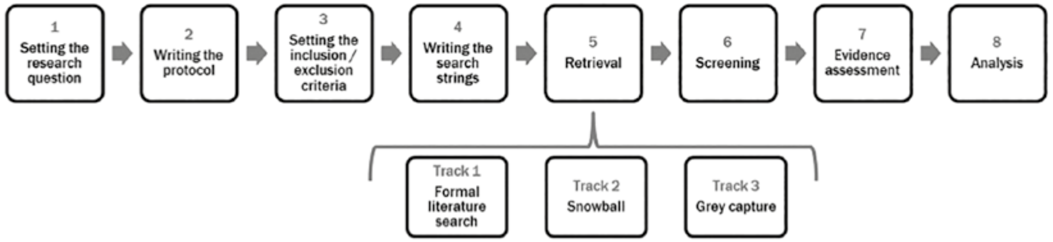


Figure 1.5.1: Literature review process as proposed by Hagen-Zanker & Mallet (2013) (from Hagen-Zanker-Mallet, 2013, p. 6)

The research presented in the thesis is explorative and intended not as an end-point but rather as a starting point for further (empirical) research and academic and societal discussion. The loss of some rigour and objectivity inherent in the chosen methodology for literature review is therefore deemed to be outweighed by the potential benefits of creating a broader base and therefore is accepted for this thesis.

The thesis applies the literature review-based research methodology as discussed above in a slightly different manner in each of the following chapters. A more detailed discussion of the particular research methodology used (e.g., search strings and inclusion/exclusion criteria) is therefore presented at the start of each chapter.

Papers 3 for Mac (Labtiva, 2016) software was used for managing documentary sources throughout the entire research project.
APA style (APA, 2013) citations are used throughout the thesis.

Gathering and Processing Empirical Data

The empirical data that is used in the thesis was collected through seven semi-structured interviews (DiCicco-Bloom & Crabtree, 2006) with representatives from companies that currently manufacture and market long-life products. A semi-structured approach was chosen for a number of reasons. The first is that the research presented in this thesis is explorative and the semi-structured interview approach allows for capturing additional information that might prove relevant, potentially contributing to new and unexpected insights. The second reason is that, as all interviewees are business professionals in managerial positions, the opportunities to go deeper into particular remarks during follow-up interviews at a later time were limited. Lastly, as the author has over 20 years of hands-on experience in commercial industrial design, the semi-structured interview approach allowed for the quick creation of rapport (DiCicco-Bloom & Crabtree, 2006) and instant exploration of emerging, but related, topics.

The interviews took place at the respective companies and were recorded using a voice recorder (after asking for and obtaining permission from the participants).

The data from the interviews was analysed and compared through repetitive, reflective immersion (DiCicco-Bloom & Crabtree, 2006) in the recordings, transcriptions and summaries, whereby the author's experience in commercial industrial design mentioned earlier provided the *"strong theoretical background"* (DiCicco-Bloom & Crabtree, 2006, p. 40) that is a prerequisite when applying this *"immersion/ crystallisation"* (DiCicco-Bloom & Crabtree, p. 40) approach. A more detailed discussion of the research methodology used for the interviews is presented in section 5.2 Methodology.

F5transkript software for Mac (Audiotranskription, 2017) software was used for transcribing the interviews.

1.6 THESIS OUTLINE

The basic structure of the thesis is presented in figure 1.6.1. As can be seen from figure 1.6.1, the thesis is divided in two main parts and a number of appendices. The first part, chapter 2 through chapter 4, aims to establish a theoretical framework for the second part of the thesis, chapter 5 through chapter 6.

PART ONE

Chapter 2 aims to provide an answer to sub-research question A: "How can product lifetime extension in a circular economy be defined within the context of industrial design?" The chapter reviews the literature on resource states and interventions for product lifetime extension and creates a comprehensive overview of the key concepts and terms that are considered relevant for industrial designers when designing for long and extended product lifetimes in a circular economy, culminating in a typology of approaches for design for preserving product integrity.

Chapter 3 aims to provide an answer to sub-research question B: "What guiding principles and design interventions can industrial designers use when designing for long and extended product lifetimes in a circular economy?" The chapter takes the typology of approaches of design for preserving product integrity presented at the end of chapter 2 as a starting point and sets out to develop the abstract design approaches into practical and actionable design strategies for preserving product integrity by reviewing the literature in search of design interventions that industrial designers can select and apply to support the various design approaches for preserving product integrity.

Chapter 4 aims to provide an answer to sub-research question C: "What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?" The chapter reviews the literature with the aim of creating a typology of circular business models for preserving product integrity in a circular economy.

PART TWO

Using data and insights gathered from the literature and company interviews, part two brings together the separate elements from the theoretical framework established in part one with the end-goal of developing a new methodology for designing products with a long or extended lifetime in a circular economy.

Chapter 5 aims to provide an answer to sub-research question D: "What guiding principles and management strategies can businesses use when creating, delivering and capturing value from long and extended product lifetimes in a circular economy?" The objective of chapter 5 is to identify or develop guiding principles and management strategies for circular business models for preserving product integrity as these determine the objectives that design strategies for preserving product integrity should help achieve. Chapter 5 identifies maximizing business model circularity as a guiding principle and introduces managing obsolescence as a management strategy for circular business models for preserving product integrity.

Chapter 6 presents the development of a design methodology for managing obsolescence. The design methodology for managing obsolescence is intended to enable industrial designers to tailor their product designs to circular business models for preserving product integrity that strive to maximize business model circularity. The objective of chapter 6 is to create a design methodology for managing obsolescence, including a heuristic framework that expresses which combinations of design interventions for preserving product integrity and circular business model types for preserving product integrity can be expected to be successful when managing obsolescence. As such, chapter 6 aims to provide an answer to sub-research question E: "To what extent are some combinations of design interventions and business model types more likely to be successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?"

Appendices

Due to the cross-disciplinary nature of its subject, the thesis reviews literature from multiple scientific domains. To provide background information for those readers who may be familiar with concepts from some of these domains but less so with concepts from others, references to the appendices are made throughout the thesis. The various appendices discuss a number of key concepts from the different scientific domains used in the thesis in a more elaborate manner. The aim of structuring the thesis in this way is to preserve the continuity of the main argument as much as possible, whilst still providing information at appropriate moments on concepts that might be less familiar to some readers.

REFERENCES CHAPTER 1: INTRODUCTION

Adamson, G. (2003). Industrial Strength Design, How Brooks Stevens Shaped Your World. Cambridge, MA, U.S.A.: the MIT press.
Allwood, J. M., Ashby, M. F., Gutowski, T. G., & Worrell, E. (2011). Material efficiency: A white paper. *Resources, Conservation and Recycling*, *55*(3), 362-381.
Antikainen, M., Lammi, M., Paloheimo, H., Rüppel, T., & Valkokari, K. (2015, December). Towards Circular Economy Business Models: Consumer Acceptance of Novel Services. In *ISPIM Innovation Symposium* **(p. 1). The International Society for Professional Innovation Management (ISPIM).**
APA (2013). *Publication Manual of the American Psychological Association* (6th ed.). Washington, DC, USA: American Psychological Association.
Audiotranskription (2017). F5transkript for Mac. Available at www.audiotranskription.de.
Bakker, C. A., den Hollander, M. C., Van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. Leidschendam, the Netherlands: TU Delft Library/ Marcel den Hollander IDCR.
Bakker, C. A., & Schuit, C. S. C. (2017). The Long View - Exploring product lifetime extension. UNEP.
Bakker, C. A., Wang, F., Huisman, J., & Den Hollander, M. C. (2014). Products That Go Round: exploring product life extension through design. *Journal of Cleaner Production 69*, 10-16.
Bartels, B., Ermel, U., Sandborn, P., Pecht, M. (2012). *Strategies to the Prediction, Mitigation and Management of Product Obsolescence.* Hoboken, NJ, USA: John Wiley & Sons Inc.
Bayus, B. L. (1991). The consumer durable replacement buyer. *Journal of Marketing 55*(1), 42–51.
Benyus, J. (1997). *Biomimicry: Innovation inspired by nature.* New York: William Morrow.
Bjørn, A., & Hauschild, M. Z. (2012). Absolute versus relative environmental sustainability. Journal of Industrial Ecology, *17*(2), 321-332.
Bocken, N. M. P., De Pauw, I., Bakker, C., & Van der Grinten, B. (2016). Product design and business model strategies for a circular economy, *Journal of Industrial and Production Engineering, 33*(5), 308-320.
Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of cleaner production*, *65*, 42-56.
Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, *45*, 9-19.
Bovea, M. D., & Pérez-Belis, V. (2012). A taxonomy of eco-design tools for integrating environmental requirements into the production design process. *Journal of Cleaner Production, 20*, 61-71.

1

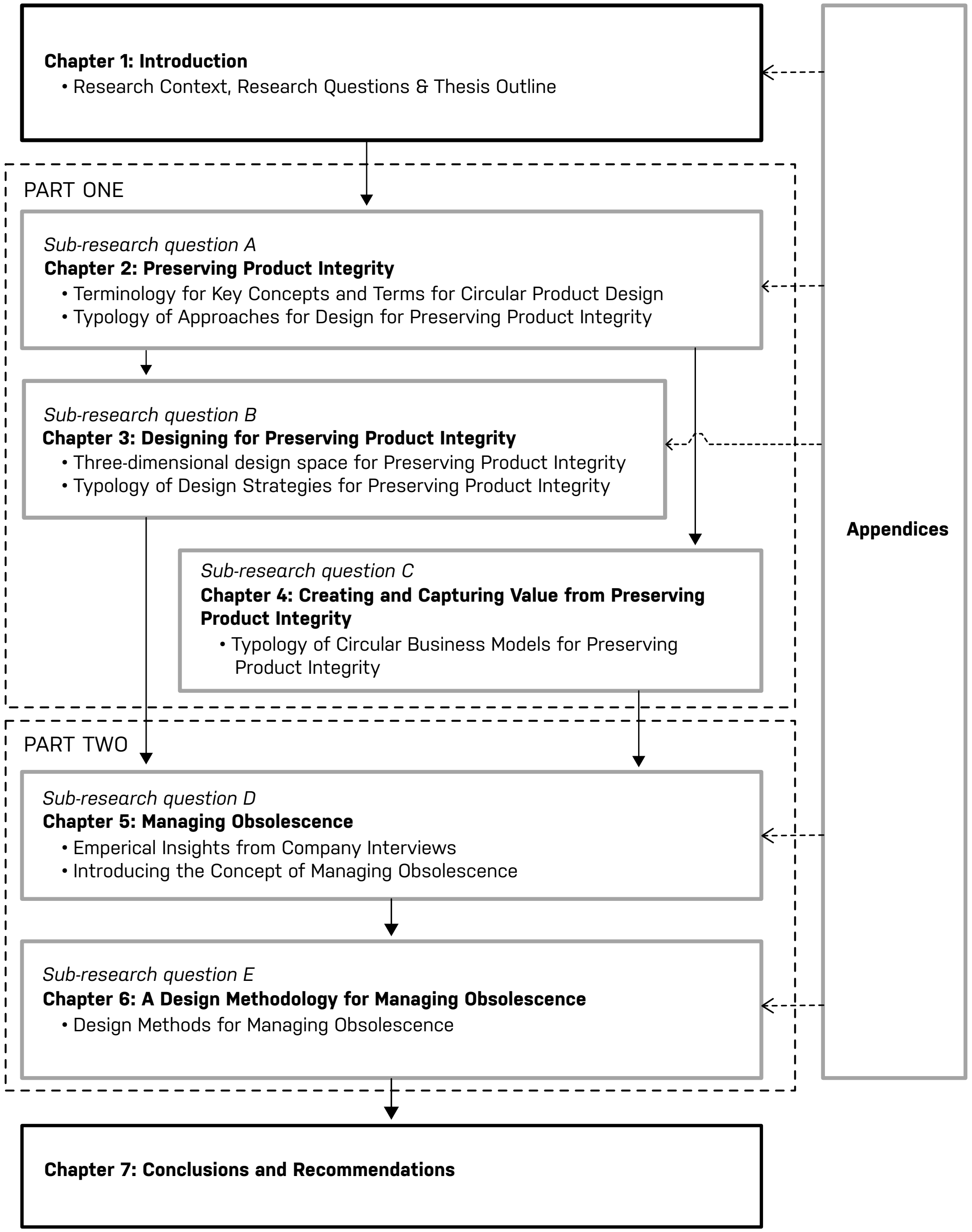


Figure 1.6.1: Thesis outline

Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. *British journal of management*, *11*(1), 1-15.

Braungart, M., McDonough, W., & Bollinger, A. (2007). Cradle-to-cradle design: creating healthy emissions–a strategy for eco-effective product and system design. *Journal of Cleaner Production*, *15*(13), 1337-1348.

Bressanelli, G., Perona, M., & Saccani, N. (2017). A new framework for assessing circular economy scenarios on durable consumer goods sectors. In *Proceedings of 4th International EurOMA Sustainable Operations and Supply Chains Forum*, February 26th-27th, 2017, Milan, Italy.

Brezet, H., & Van Hemel, C. (1997). *Ecodesign: A promising approach to sustainable production and consumption*. Paris, France: UNEP.

Brown, T., & Katz, B. (2011). Change by design. *Journal of Product Innovation Management 28*(3): 381–383.

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

Burns, B. (2010). Re-evaluating Obsolescence and Planning for It. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 39-60). Farnham, Surrey, UK: Gower Publishing Limited.

Butti, L. (2012). Birth and death of waste. *Waste management, 32*, 1621-1622.

Chapman, J. (2009). Design for (Emotional) Durability. *Design Issues 25*(4).

Charter M., & Tischner U. (2001). Sustainable Solutions. Developing Products and Services for the Future. Sheffield, UK: Greenleaf.

Comerasamy, H. (2017). *Literature based research methodology*. Retrieved September 15th, 2017 from https://www.slideshare.net/huguette_comerasamy/literature-based-research-methodology?qid=cd8a2c3e-93a7-4b58-be34-b3f18307a802&v=&b=&from_search=3.

Cooper, T. (2010). The Significance of Product Longevity. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 3-36). Farnham, Surrey, UK: Gower Publishing Limited.

Cross, N. (1984). *Developments in design methodology*. John Wiley & Sons.

Daalhuizen, J. J. (2014). *Method Usage in Design – How methods function as mental tools for designers* (Doctoral dissertation, Delft University of Technology, Delft, the Netherlands).

De los Rios, I. C., & Charnley, F. J. (2016). Skills and capabilities for a sustainable and circular economy: The changing role of design. *Journal of Cleaner Production, 160*, 109-122.

De Pauw, I. C. (2015). *Nature-Inspired Design: Strategies for Sustainable Product Development* (Doctoral dissertation, Delft University of Technology, Delft, the Netherlands).

DiCiccoBloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical education*, *40*(4), 314-321.

EC (European Commission) (2009a). *Directive 2009/125/EC of the European Parliaments and the Council of 21 October 2009 Establishing a Framework for the Setting of Ecodesign Requirements for Energy-related Products (Recast)*, vol. 2011. Brussels, Belgium: European Commission Energy.

EC (2009b). *Waste Framework Directive (2008/98/EC)* or *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*. Retrieved October 30th, 2015 from http://eur-lex.europa.eu/legal- content/EN/TXT/?uri=CELEX:32008L0098.

EC (2015a). *The Durability of Products – Standard Assessment for the Circular Economy under the Eco-Innovation Action Plan.* Luxembourg, Luxembourg: Publications Office of the European Union. Retrieved July 9th, 2016 from http://bookshop.europa.eu/en/the-durability-of-products-pbKH0115726/.

EC (2015b). *Closing the loop - An EU action plan for the Circular Economy.* Retrieved July 10th, 2016 from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX% 3A52015DC0614.

EC (2017a). *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the implementation of the Circular Economy Action Plan.* Retrieved September 15th, 2017 from http://ec.europa.eu/environment/circular-economy/implementation_report.pdf.

EC (2017b). *A longer lifetime for products: benefits for consumers and companies, European Parliament resolution of 4 July 2017 on a longer lifetime for products: benefits for consumers and companies (2016/2272(INI)), Provisional text P8_TA-PROV(2017)0287.* Retrieved September 15th from http://www.europarl.europa.eu/sides/getDoc.do?-pubRef=-//EP//NONSGML+TA+P8-TA-2017-0287+0+-DOC+PDF+V0//EN.

Ehrenfeld, J. (2008). *Sustainability by design. A Subversive Strategy for Transforming Our Consumer Culture*. Yale University: New Haven, CT, USA.

EMF (Ellen MacArthur Foundation) (2012). *Towards the Circular Economy Vol. 1 - An Economic and Business Rationale for an Accelerated Transition.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.

EMF (2013). *Towards the Circular Economy Vol. 2 - Opportunities for the Consumer Goods Sector.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2014). *Towards the Circular Economy Vol. 3 - Accelerating the scale-up across global supply chains*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2015). *Growth Within: a circular economy*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EPEA (Environmental Protection Encouragement Agency), 2004. *Plug-In to eCycling - Guidelines for Materials Management*. Retrieved July 10th, 2016 from www.epeat.net/documents/reference-docs/epa-plug-in-to-ecycling-guide-lines.2004-05.pdf.
Faber, N., Jorna, R., & Van Engelen, J. O. (2005). The Sustainability of "Sustainability"—A Study into the Conceptual Foundations of the Notion of "Sustainability". *Journal of Environmental Assessment Policy and Management, 7*(01), 1-33.
Faste, T., & Faste, H. (2012, August). Demystifying "design research": Design is not research, research is design. In *IDSA Education Symposium* **(Vol. 2012, p. 15).**
Financial Times (2017). *Culture clash is biggest obstacle to Unilever takeover*. Retrieved March 15th, 2017 from www.ft.com/content/f0c96d72-f537-11e6-95ee-f14e55513608.
Freedman, L. (2013). *Strategy - a history.* New York, NY, USA: Oxford University Press.
Geisendorf, S., & Pietrulla, F. (2017). The circular economy and circular economic concepts—a literature analysis and redefinition. *Thunderbird International Business Review*.
Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2016). The Circular Economy - A New Sustainability Paradigm? *Journal of Cleaner Production 143*, 757-768.
Gharfalkar, M., Ali, Z. & Hillier, G. (2016). Clarifying the disagreements on various reuse options: Repair, recondition, refurbish and remanufacture. *Waste Management & Research, 34*(10), 995-1005.
Govindan, K., Soleimani, H., Kannan, D. (2014). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research 240*, 603–626.
Graedel, T. E., & Allenby, B. R. (2003). *Industrial Ecology* (2nd ed.). Upper Saddle River, New Jersey, USA: Pearson Education, Inc.
Graedel, T. E., Harper, E. M., Nassar, N. T., & Reck, B. K. (2015). On the materials basis of modern society. *Proceedings of the National Academy of Sciences*, *112*(20), 6295-6300.
Graham, B. (2006). *The Intelligent Investor: The definitive book on value investing* (Revised ed.). New York, NY, USA: HarperBusiness.
Grosse-Hering, B., Mason, J., Aliakseyeu, D., Bakker, C. A., & Desmet, P. (2013, April). Slow design for meaningful interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 3431-3440). ACM.
Guide Jr., V. D. R., Harrison, T. P., & Van Wassenhove, L. N. (2003). The challenge of closed-loop supply chains. *Interfaces, 33*(6), 3-6.
Guide Jr., V. D. R., & Van Wassenhove, L. N. (2009). OR FORUM—The evolution of closed-loop supply chain research. *Operations research, 57*(1), 10-18.
Hagen-Zanker, J., & Mallett, R. (2013). *How to do a rigorous, evidence-focused literature review in international development, A Guidance Note*. London: Overseas Development Institute.
Heiskanen, E. (1996). *Conditions for Product Life Extension.* National Consumer Research Centre Working Papers 23.
Heskett, J. (1987). *Industrial design*. London, UK: Thames and Hudson.
Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology*, *21*(3), 517-525.
Hoornweg, D., & Bhada-Tata, P. (2012) *What a Waste - A Global Review of Solid Waste Management*. World Bank Report 15. Retrieved April 4th, 2017 from http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf
Huisman, J., Van der Maesen, M., Eijsbouts, R. J. J., Wang, F., Baldé, C. P., & Wielenga, C. A. (2012). The Dutch WEEE Flows. *United Nations University, ISP–SCYCLE, Bonn, Germany*, *15*.
IDSA (Industrial Designers Society of America) (2017). Industrial Design Defined [Web log post]. Retrieved September 3rd, 2017 from http://www.idsa.org/news/dblog/what-id.
Jackson, T. (2009). *Prosperity without growth - Economics for a finite planet*. Oxon, U.K.: Earthscan.
Kiatkittipong, W., Wongsuchoto, P., Meevasana, K., & Pavasant, P. (2008). When to buy new electrical/electronic products? *Journal of Cleaner Production*, *16*(13), 1339-1345.
Kim, H. C., Keoleian, G. A. & Yuhta, A. H. (2006). Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost. *Energy Policy, 34*, 2310-2323.
Köhler, A. R. (2013). Material Scarcity: A Reason for Responsibility in Technology Development and Product Design. *Science and Engineering Ethics, 19*, 1165-1179.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, *143*(C), 37-46.
Kotler, P., 1984. *Marketing Management* (5th ed.), London, UK: Prentice/Hall International.
Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K. H., Haberl, H. & Fischer-Kowalski, M. (2009). Growth in global material use, GDP and population during the 20th century. *Ecological Economics, 68*, 2696-2705.
Kuijer, S. C. (2014). *Implications of social practice theory for sustainable design* (Doctoral dissertation, Delft University of Technology, the Netherlands).
Laptiva (2016). Papers 3 for Mac. Available at http://papersapp.com.
Levhari, D. & Srinivasan, T. N. (1969). Durability of Consumption Goods: Competition versus Monopoly. *The American Economic Review 59*(1), 102-107.
Lewandowski, M. (2016). Designing the Business Models for Circular Economy - Towards the Conceptual Framework. *Sustainability 8*(43): 1-28.
Lifset, R. & Graedel, T. E. (2002). Industrial ecology: goals and definitions. In Ayres, R.U. (Ed.), *A handbook of industrial ecology* (pp. 3-15). Cheltenham, UK: Edward Elgar publishing.
Linder, M., & Williander, M. (2017). Circular business model innovation: inherent uncertainties. *Business Strategy and the Environment, 26*(2), 182-196.
Linton, D. & Jayaraman, V. (2005). A Framework for Identifying Differences and Similarities in the Managerial Competencies Associated with Different Modes of Product Life Extension. *International Journal of Production Research 43*(9), 1807-1829.
Luttropp, C., & Lagerstedt, J. (2006). EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development. *Journal of Cleaner Production*, *14*(15), 1396-1408.
Malone, T. W., Weill, P., Lai, R. K., D'Urso, V. T., Herman, G., Apel, T. G., & Woerner, S. (2006). *Do some business models perform better than others*? Retrieved November 20th, 2017 from https://mpra.ub.uni-muenchen.de/4751/1/MPRA_paper_4751.pdf
Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: an emerging field of research and its prospects. *Research Policy 41*, 955-967.
Maxwell, D., & Van der Vorst, R. (2003). Developing sustainable products and services. *Journal of Cleaner Production*, *11*(8), 883-895.
Mayo, S. (1993). Myth in Design. *International Journal of Technology and Design Education, 3*(1), 41-52.
McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things.* New York, NY, USA: North Point Press.
McKinsey Global Institute (2011). *Resource Revolution: Meeting the World's Energy, Materials, Food, and Water Needs.* Retrieved July 9th, 2017 from www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/resource-revolution.
Meadows, D., Randers, J., & Meadows, D. (2004). *Limits to Growth – The 30-Year Update.* White River Junction, VT, USA: Chelsea Green Publishing Company.
Mont, O. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production, 10*(3), 237-245.
Mont, O. (2004). *Product-Service Systems: Panacea or Myth?* (Doctoral thesis, Lund University, Lund, Sweden).
Mont, O., Dalhammar, C., & Jacobsson, N. (2006). A new business model for baby prams based on leasing and product remanufacturing. *Journal of Cleaner Production*, *14*(17), 1509-1518.
Mugge, R. (2007). *Product Attachment* (Doctoral thesis, Delft University of Technology, Delft, the Netherlands).
Oakdene Hollins Ltd. (2007). *An Analysis of the Spectrum of Re-use.* Aylesbury, UK: Oakdene Hollins Limited. (Document reference: DEFR02 089 Reuse Review.doc).
Pérez-Belis, V., Bakker, C., Juan, P., & Bovea, M. D. (2017). Environmental performance of alternative end-of-life scenarios for electrical and electronic equipment: A case study for vacuum cleaners. *Journal of Cleaner Production*, *159*, 158-170.
Pigosso, D. C. A., McAloone, T. C. & Rozenfeld, H. (2015). Characterization of the state-of-the-art and identification of main trends for ecodesign tools and methods: Classifying three decades of research and implementation. *Journal of the Indian Institute of Science, 94*(4), 405-427.
Porter, M.E. (1980). *Competitive strategy - Techniques for Analysing Industries and Competitors.* New York, NY, USA: The Free Press.
Prakash, S., Dehoust, G., Gsell, M., Schleicher, T. & Stamminger, R. (2016). *Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen 'Obsoleszenz'*. Dessau-Roßlau, Germany: Umweltbundesamt.
Prendeville, S., & Bocken, N. (2017). Design for remanufacturing and circular business models. In *Sustainability Through Innovation in Product Life Cycle Design* (pp. 269-283). Springer Singapore.

Rainey, D.L. (2005). *Product Innovation – Leading Change through Integrated Product Management*. New York, USA: Cambridge University Press.
Reim, W., Parida, V., & Örtqvist, D. (2015). Product–Service Systems (PSS) business models and tactics–a systematic literature review. *Journal of Cleaner Production*, *97*, 61-75.
Rizos, V., Behrens, A., Van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M. & Topi, C. (2016). Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers. Sustainability 8(11) 1212: 1-18.
Rojo, F., Roy, R., & Shebab, E. (2010). Obsolescence management for long-life contracts: state of the art and future trends. *International Journal of Advanced Manufacturing Technology 49*, 1235-125.
Roozenburg, N. F. M., & Eekels, J. (1995). *Product Design: Fundamentals and Methods*. Chichester, U.K.: John Wiley & Sons.
Seiffert, M., & Loch, C. (2005). Systemic thinking in environmental management: support for sustainable development. *Journal of Cleaner Production 13*(12), 1197-1202.
SER (Sociaal Economische Raad) (2016). Werken aan een circulaire economie: geen tijd te verliezen (Tr.: Working towards a circular economy: no time to lose). Retrieved September 3rd, 2017 from www.ser.nl/~/media/db_adviezen/2010_2019/2016/circulaire-economie.ashx.
Sirkin, T., & ten Houten, M. (1994). The cascade chain: a theory and tool for achieving resource sustainability with applications for product design. *Resources, Conservation and Recycling*, *10*(3), 213-276.
Stahel, W. R. 1994. The utilization-focused service economy: Resource efficiency and product-life extension. In B. R. Allenby and D. Richards (Eds.), *The greening of industrial ecosystems* (pp. 23–37). Washington, DC: National Academies Press.
Stahel, W. R. (2010). *The Performance Economy (2nd ed.)*, Hampshire, UK: Palgrave Macmillan Hampshire.
Stevels, A. L. N. (2007). *Adventures in EcoDesign of Electronic Products 1993-2007*. Delft, the Netherlands: Delft University of Technology, Faculty of Industrial Design Engineering.
Stout, L. (2017). *Corporations Don't Have to Maximize Profits*. Retrieved May 10th, 2017 from www.nytimes.com/roomfordebate/2015/04/16/what-are-corporations-obligations-to-shareholders/corporations-dont-have-to-maximize-profits.
Swan, P. L. (1970). Durability of Consumption Goods. *The American Economic Review 60*(5), 884-894.
Tasaki, T., Motoshita, M., Uchida, H., & Suzuki, Y. (2013). Assessing the replacement of electrical home appliances for the Environment. *Journal of Industrial Ecology*, *17*(2), 290-298.
Tischner, U., Schminke, E., Rubik, F., & Prösler, M. (2000). *How to do EcoDesign? A guide for environmentally and economically sound Design.* In collaboration with B. Dietz, S. Maßelter & B. Hirschl, edited by the German Federal Environmental Agency. Frankfurt am Main, Germany: Verlag form Praxis.
Tukker, A. (2004). Eight Types of Product– Service System: Eight Ways to Sustainability? Experiences from Suspronet. *Business Strategy and the Environment 13*, 246–260.
Tukker, A. (2015). Product services for a resource-efficient and circular economy - a review. *Journal of Cleaner Production, 97*, 76-91.
Tukker, A., & Tischner, U. (2006). *New Business for Old Europe – Product-Service Development, Competitiveness and Sustainability.* Sheffield, UK: Greenleaf Publishing Limited.
Tukker, A., Van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In A. Tukker and U Tischner (Eds.), N*ew Business for Old Europe - Product-service development, competitiveness and sustainability* (pp. 22-34). Sheffield, UK: Greenleaf Publishing Ltd.
UNEP (2010). *Metal stocks in society, scientific synthesis*. Paris, France: United Nations Environment Programme, Division of Technology, Industry and Economics - International Panel for Sustainable Resource Management.
Van Boeijen, A. G. C, Daalhuizen, J. J., Zijlstra, J. J., & Van der Schoor, R. S. A. (eds.) (2013). *Delft Design Guide.* Amsterdam, The Netherlands: BIS Publishers.
Van Hemel, C. G. (1998). *Ecodesign empirically explored* (Doctoral dissertation, Delft University of Technology, Delft, the Netherlands).
Van Nes, N. (2003). Replacement of Durables: Influencing product life time through product design (Doctoral thesis, Erasmus University Rotterdam, Rotterdam, the Netherlands).
Van Nes, N., & Cramer, J. (2005). Influencing Product Lifetime through Product Design. *Business Strategy and the Environment 14*, 286-299.
Vezzoli, C. & Manzini, E. (2008). *Design for Environmental Sustainability*. London, UK: Springer-Verlag London Limited.
WBSCD (World Business Council for Sustainable Development) (2010). *Vision 2050. The New Agenda for Business*. Retrieved April 5th, 2017 from www.wbcsd.org/Overview/About-us/Vision2050/Resources/Vision-2050-The-new-agenda-for-business.
Webster, K. (2015). *The circular economy: A wealth of flows*. Cowes, UK: Ellen MacArthur Foundation.
Wever, R., & Vogtländer, J. (2015). Design for the Value of Sustainability. In J. van den Hoven, P.E. Vermaas, I. van de Poel (Eds.), *Handbook of Ethics, Values, and Technological Design* (pp. 513-549). Dordrecht, the Netherlands: Springer Science+Business Media.
World Design Organization (2017). Industrial Design definition. Retrieved November 20th, 2017, from http://wdo.org/about/definition/
WRAP (Waste and Resources Action Programme) (2017). Circular economy definition. Retrieved March 29th, 2017 from www.wrap.org.uk/about-us/about/wrap-and-circular-economy.
Yu, J., Williams, E., & Ju, M. (2010). Analysis of material and energy consumption of mobile phones in China. *Energy Policy*, *38*(8), 4135-4141.
Zheng, L., Terpenny, J., & Sandborn, P. (2016). Design refresh planning models for managing obsolescence. *IIE Transactions 47*(12), 1407-1423.

2

PRESERVING PRODUCT INTEGRITY

How can product lifetime extension in a circular economy be defined within the context of industrial design?

Chapter 2: Preserving Product Integrity is an adaptation of Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology, 21* (3), 517-525.

2.1 INTRODUCTION

The objective of chapter 2 is to create a comprehensive overview of the key concepts and terms that are considered relevant for industrial designers when designing for long and extended product lifetimes in a circular economy, culminating in a typology for design approaches for preserving product integrity.

When the absolute idea of a circular economy as was described in chapter 1 is accepted, it follows that discarding obsolete products and/or their constituent materials that cannot profitably be recovered as waste – as is common and accepted practice in our current linear economy – is no longer an option in a circular economy. As such, the ability to decide correctly on the most economically and environmentally effective type and *sequence* of interventions for preserving and reclaiming value that is embedded in products becomes essential. Deciding on one type and sequence of interventions over another requires a structured and unambiguous terminology for resource states and interventions for preserving and reclaiming the added economic value that is embedded in products. This terminology needs to be comprehensive, have sufficient resolution to allow for unequivocal discrimination between the different options and can no longer include the concept of waste. Much of the terminology that is used in the current literature for describing various resource states and interventions for preserving and reclaiming added economic value, however, is ambiguous with regard to meaning as well as structure (Oakdene Hollins Ltd., 2007; Gharfalkar et al., 2016) and frequently refers to the concept of waste. For these reasons, the present terminology is deemed insufficient for use in a circular economy and a new, unambiguous, comprehensive and clearly structured set of definitions of resource states and interventions for product lifetime extension is needed (Gharfalkar et al., 2016). Since the role of industrial product designers could more abstractly be viewed as the development of solutions that match the needs of users with the needs of businesses, making use of the findings of research and within the legal and regulatory boundaries provided by the government, the thesis suggests that a new, comprehensive and unambiguous typology intended for use by industrial designers could also prove useful to researchers, business professionals and government employees in facilitating interdisciplinary communication and alignment of future actions in support of a circular economy.

2.2 METHODOLOGY

A literature review is done in order to create a comprehensive overview of the key concept and terms that might be relevant for product design for a circular economy. The literature review is based on the procedures described by Hagen-Zanker and Mallet (2013) as discussed in section 1.5 Research Design and for the research presented in chapter 2 draws predominantly from scientific publications in the fields of industrial ecology, eco-design, and sustainable product design, and includes (mostly grey literature) on the circular economy concept. We compiled the initial body of literature, limited to documentary sources in the English, Dutch or German language but without limits to publication date, from the search results returned by Google Scholar, for search terms related to sustainable product design, eco-design, and circular economy. The initial list of search terms consists of (combinations of): circular economy, classification*, closed loop, definition*, description*, eco-design, lifetime*, lifespan*, maintenance, obsolescence, planned obsolescence, product, product design, product life*, recondition*, recover*, refurbish*, remanufactur*, recycl*, reuse, renewable energy, repair, resource*, reverse logistics, standard, terminology, upgrad* and waste. Using snowballing, we added new keywords that emerged to the initial set.

The results of the searches were scan-read to determine, based on the over 20 years of hands-on experience of the author in the fields of commercial industrial design and sustainable design and erring on the side of caution, whether they pertained to product design, product design for extended lifetimes, product lifetime, circular economy, sustainability and business in a manner that was potentially relevant to the topic of the research. Clearly irrelevant results, for example highly technical econometric or computing related papers, were discarded before storing the results in a software-based retrieval system and assigning (additional) keywords to them for later reference.

In total, we studied over 250 articles in detail order to gain a deeper understanding, identify the *seed literature* (works of research on the topic considered as fundamental in the specific field) and to detect similarities, discrepancies, inconsistencies, and/or contradictions (Hart 2011).

2.3 ECO-DESIGN VERSUS CIRCULAR PRODUCT DESIGN: FUNDAMENTAL DIFFERENCES

One of the guiding principles of eco-design is the waste hierarchy, described in the European Waste Framework Directive (EC, 2008). The waste hierarchy details a priority order for managing waste, moving from prevention of waste (the preferred option), to reuse, recycling, other recovery (e.g., energy recovery), and disposal (the least preferred option). For eco-design, the goal is to strive for prevention over reuse, and for reuse over recovery, etc. Waste is defined in the European Waste Framework Directive as *"any substance or object which the holder discards or intends or is required to discard"* (EC, 2008, p. L312/9).

The current definitions of prevention, reuse, recovery, and recycling all hinge on the assumption that a product at a certain point in time inevitably will become waste. The waste hierarchy, for instance, defines prevention as: *"measures taken before a substance, material or product has become waste"* (EC, 2008, p. L312/10). The definition of reuse is: *"any operation by which products or components that are not waste are used again for the same purpose for which they were conceived"* (EC, 2008, p. L312/10). , and the definition of recovery is: *"any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy"* (EC, 2008, p. L312/10) This shared reliance on waste as a central defining entity renders them virtually meaningless in context of a circular economy, where waste does not exist. It provides a clear indication of the need to examine the underlying concepts these terms aim to express and, if so, to reconsider and adjust their wording accordingly.

The waste hierarchy has been critiqued by Behrens, Giljum, Kovanda and Niza (2007) for not necessarily having a positive impact on dematerialization and decoupling, given that it focuses only on waste and does not address material inputs directly, nor consider economic output. Van Ewijk and Stegemann (2014), in addition, provides a critique relating to the hierarchy's priority orders. First, they argue, inclusion of an option in a priority order legitimizes its existence (i.e., disposal). Second, the common understanding is that one needs to move up the hierarchy rather than necessarily achieve the highest outcome. It is about the direction of change rather than the end goal, which illustrates the relative nature of the waste hierarchy (and of eco-design).

With the Inertia Principle, Stahel (2010) introduced a guiding principle for circular design: *"Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system"* (p. 195). For product designers, the Inertia Principle is about product integrity, which we define here as the extent to which a product remains identical to its original (e.g., as manufactured) state, over time. The starting point is the original product, and the intention of the Inertia Principle is to keep the product in this state, or in a state as close as possible to the original product, for as long as possible, thus minimizing and ideally eliminating environmental costs when performing interventions to preserve or restore the product's added economic value over time. This illustrates the absolute nature the Inertia Principle (i.e., it is aimed at a utopian goal).

Because the Inertia Principle starts from the highest level of product integrity, it is understood that moving down the hierarchy may be inevitable in the real world but is not the preferred direction. From a product design perspective, recycling is the least preferred option given that it involves the destruction of a product's integrity. The recycling process involves the dismantling and disintegration of a product and its constituent components and the subsequent reprocessing of the product's materials.

If we accept that product design for a circular economy, or circular product design, is guided by the Inertia Principle and the concept of product integrity, the next step is to develop a set of key concepts and terms that incorporate these principles and that include the fact that a product can, in principle, not become waste.

2.4 KEY CONCEPTS FOR CIRCULAR PRODUCT DESIGN

For a circular economy to mimic a closed-loop system as closely as possible from a material flow perspective, resources that have entered the circular economy have to remain accounted for at all times: before, during, and after their lifetime as useful products. It follows that product lifetime is a key concept in a circular economy.

Products Become Obsolete/Product Use Cycle/Product Lifetime

Product lifetime is often equated with the time span during which a product is functional (e.g., Murikami, Oguchi, Tasaki, Daigo & Hashimoto, 2010). However, functionality is considered an insufficient criterion for two reasons. First, many products are discarded while still in perfect working order (Oswald & Reller, 2011; Chapman, 2005; Van Nes, 2003; Bayus, 1991). Second, products can be temporarily out of order without immediately being discarded. A flat tire is no reason to discard a bicycle. We therefore propose to define product lifetime in terms of obsolescence. A product becomes obsolete if it is no longer considered useful or significant by its user (Burns, 2010). The literature distinguishes different types of obsolescence or reasons for products being discarded. Burns (2010), for instance, discerns aesthetic obsolescence (i.e., products that have become outmoded), social obsolescence (i.e., products that have become outlawed), technological obsolescence, and economic obsolescence. Further examples include logistical and functional obsolescence (Bartels et al., 2012; Cooper 2010; Feldmann & Sandborn 2007; Tomczykowski 2001).

However, reduced to its essence, all obsolescence ultimately is a loss of perceived value (i.e., desire or affinity) of the product and/or system, triggered, in some instances, by reduced functionality at the product and/or system side (Box, 1983). The state of obsolescence does not have to be permanent. It can often be reversed, giving a product a new lease of life. Expressing product lifetime in terms of obsolescence and acknowledging that obsolescence can often be reversed leads to the following newly synthesized definitions:

Product use cycle is the duration of the period that starts at the moment a product is released for use after manufacture or recovery and ends at the moment a product becomes obsolete.

Product lifetime is the duration of the period that starts at the moment a product is released for use after manufacture and ends at the moment a product becomes obsolete beyond recovery at product level.

Recovery is a term for any operation with the primary aim of reversing obsolescence. Note that this definition of recovery rather differs from the one presented in the European Waste Framework Hierarchy (EC, 2008) (see section 2.3 Eco-Design versus Circular Product Design: Fundamental Differences).

From the above definitions, it follows that products can have one or more use cycles, but only one lifetime. As long as a product's obsolescence can be reversed, a new use cycle can be started. If, however, resources can only be recovered at the expense of permanently destroying product integrity, that is, through recycling at material level, the product lifetime ends. By using the term obsolescence in the definitions of product use cycle and product lifetime, it is acknowledged that the duration of product use cycles and product lifetime are not solely determined by the physical properties of the isolated product (Cooper, 2010), but rather by the perceived value within its wider context. The following excerpt by Bayus (1991) provides insight into some of these contextual factors:

> Though product reliability has increased, and service incidence has declined over time for home appliances because of advancements in technology, studies suggest that consumers are not necessarily interested in products with longer lifetimes. Consumers replace working units before they wear out for a variety of reasons, including style/ fashion preferences, product features and technology advances, and price and sales promotions. Surveys further indicate that specific reasons for replacement purchases include failure or unreliable performance of the current product, changed family circumstances (e.g., recent marriage, larger family size, household move), and improved financial circumstances (p. 43).

Bayus' observation that *"consumers replace working units before the wear out"* was echoed by Mugge (2007) who, referencing Van Nes (2003), stated that *"many products are replaced while they are still functioning properly: Only 22% of the products are completely malfunctioning at the time of replacement"* (p. 22). Chapman (2005) and Oswald and Reller (2011) also confirmed that many products are disposed of while still in perfect working order.

Product lifetime can therefore not be considered an engineering quality that can be objectively designed into a product (Stahel, 1986). Given the many factors potentially affecting product lifetime, we suggest that industrial designers cannot design products with an extended lifetime but can only *design a potential for* an extended product lifetime into a product. The degree to which this potential is actually realized is determined to a large extent by factors *other* than the design of the tangible products. It follows that interventions to deliberately lengthen a product's overall lifetime can thus be aimed at modifying the physical properties of the product, as well as at altering the product's position relative to its wider context.

Presource/Leakage/Recovery Horizon

Until now, the term assigned to obsolete products and their embedded resources in a linear economy mostly depended on their location. Unused products, tucked away in people's homes, are said to be *hibernating* (Oswald & Reller, 2011) or called *stock* (Graedel et al., 2013) and are destined to become waste. To redefine obsolete products and their embedded resources in a circular economy, making their designation independent of location and distinguishing them from virgin resources, we propose a newly synthesized definition for these obsolete products awaiting recovery. The new term is a contraction of *product* and *resources*, reflecting their lineage and potential economic value for production:

Presource is a term for obsolete products awaiting recovery.

The concept of presource pertains to the whole product as it became obsolete and as such does not discriminate between components, parts, or materials. Depending on the intervention that is applied to recover the obsolete products awaiting recovery, presource is converted into products or components (e.g., though, repair, refurbishing, and remanufacturing) or materials (e.g., recycling).

Although the circular economy knows no waste, in reality there will always be dissipative losses. These are defined by Ciacci, Reck, Nassar and Graedel (2015) as the flows of materials from the anthroposphere (i.e., human systems) to the biosphere (i.e., environment) in a manner that makes their future recovery extremely difficult, if not impossible. Examples of such dissipative losses are platinum and cerium released from autocatalytic converters, the wear of rubber tires, and the evaporation of chemicals contained in solvents, lubricants, and coolants. In this thesis, building on the description of dissipative losses by Ciacci et al. (2015), we propose the term leakage:

Leakage is a term for products or their components/materials that flow from the circular economic system to the biosphere, and that cannot be recovered at the present time.

The integration of the temporal aspect in the above definition of leakage suggests that what is considered leakage today, could tomorrow be recovered, given that recovery methods, processes, and facilities are likely to evolve over time. This leads to the concept of recovery horizon. Recovery horizon is defined as:

Recovery horizon is the present limit beyond which products or their components cannot be recovered.

Summarizing, the goal of a circular economy is to have as many resources as possible remain part of the economic system and, when needed, to return them from the obsolete state (presources) to the non-obsolete state as quickly and efficiently as possible, while all the time minimizing leakage and pushing the recovery horizon.

2.5 DESIGN FOR PRESERVING PRODUCT INTEGRITY: A TYPOLOGY FOR DESIGN APPROACHES

Following the Inertia Principle and the concept of product integrity, designers in a circular economy should first aim to prevent a product from becoming obsolete and, second, make sure that presources can be recovered with the highest level of integrity (i.e., reversing obsolescence). These two goals can be pursued at the level of products and components (this will be referred to as *design for preserving product integrity* or at the level of materials (referred to as *design for recycling*). Circular product design includes both design for preserving product integrity and design for recycling (see figure 2.5.1). With recycling (either conventional or biocycling), the product's integrity is lost. The designer's goal when designing for recycling is to ensure that the product's materials can be recycled as efficiently and effectively as possible and be looped back into the economic system.

In the remainder of this thesis, the focus will be on design for preserving product integrity, because design for recycling is an established concept that has been described extensively in the literature (for a recent review, see for example De Aguiar et al., 2017).

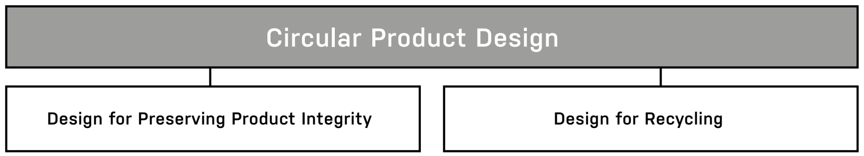


Figure 2.5.1: Circular product design includes both design for preserving product integrity and design for recycling.

Design Directions for Preserving Product Integrity: Resisting Obsolescence, Postponing Obsolescence and Reversing Obsolescence

Designers can help prevent a product from becoming obsolete by creating products with a high emotional and physical durability, that are intended to be used for a long time. In other words, such products *resist* obsolescence. An example could be a comfortable, sturdy pair of leather boots. Designers can also create products that are easy to maintain and/or upgrade, thus enabling extended use. Leather boots are relatively easy to maintain, for instance—all they require is a regular polish. This helps *postpone* obsolescence. Design approaches for long use and extended use, that resist or postpone obsolescence, prolong a product's use cycle and thus extend its lifetime.

In order to facilitate recovery (*reversing obsolescence*), designers can create products that are, for instance, easy to repair or refurbish. A hole in a leather boot's sole renders the boot obsolete. The hole can, however, easily be repaired by having a cobbler resole the boot, thus giving the boot a new use cycle and extending its lifetime.

A Typology for Design Approaches for Preserving Product Integrity

A typology for design approaches for preserving product integrity in a circular economy is depicted in figure 2.5.2. Each of the three design directions (i.e., resisting obsolescence, postponing obsolescence and reversing obsolescence) is supported by one or more design approaches: The design direction postponing obsolescence for example is supported by the design approaches designing for maintenance and designing for upgrading. Each individual design approach aims to facilitate a specific intervention for preserving product integrity. The different design approaches for each of the three main design directions for preserving product integrity will be described and defined in more detail in the subsequent sub-sections. We will show that taking an industrial design perspective on countering obsolescence requires existing definitions to be adapted and expanded, because they need to include aspects that were not considered when product lifetime was defined exclusively in terms of functionality, such as brand (Simões & Dibb 2001; Kotler, 1984), warranty (Ijomah, Childe & McMahon, 2004), cosmetic condition (Van Nes & Cramer, 2005), and the need to control access to intellectual property (Sundin, 2004). References to these aspects are included in the new definitions because they significantly affect perceived use value (and thus the onset of obsolescence) as well as the range of options for design interventions.

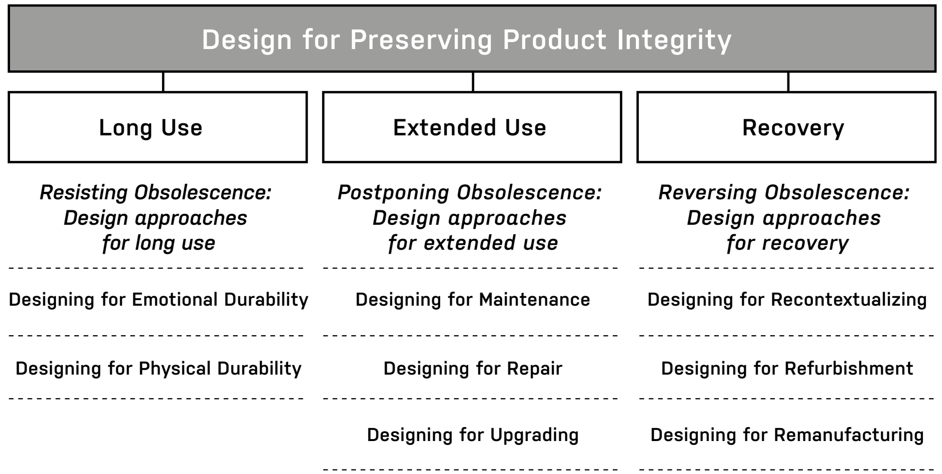


Figure 2.5.2: A typology for design approaches for preserving product integrity in a circular economy.

2.5.1 Resisting Obsolescence: Designing for Emotional and Physical Durability

Emotional Durability

Some products never seem to fall out of grace. The leather suitcases of the Saddleback Leather Company (Saddleback Leather Co., 2016) for example, that carry a 100-year warranty and, in their scuffmarks and scratches incurred during use, contain a record of their users' toils and travels. Products from this category manage to remain wanted over time and sometimes are even passed down across generations. In many cases this happens not in spite of, but precisely because of their accumulated imperfections. These products are seemingly immune to obsolescence and possess an intangible quality that Chapman (2009) called *"emotional durability"* (p. 29):

> Emotionally durable products dodge the deflowering gaze of waste by possessing interlaced layers of meaning that grow and adapt with the user, to ensure that the subject and the object co-evolve, rather than the one-sided development that usually takes place, where the user outgrows the static product in a handful of weeks, or days. 'After all, what people basically want is a well-functioning and up to date product that meets their altering needs; the dynamic nature of this desire requires a similar approach – the development of dynamic and flexible products' (Chapman, 2008, p. 15).

Based on the descriptions of Chapman (2008, 2009), we propose the following definition:

Emotional durability is the ability of products to remain wanted by users over a long period of time.

Emotional durability depends on the feelings and emotions of users. The fact that a product is in perfect working order is no guarantee that it won't fall prey to obsolescence (Oswald & Reller, 2011; Mugge, 2007; Chapman, 2005; Van Nes, 2003; Bayus, 1991). Conversely, products that have broken down may repeatedly be brought back from their state of obsolescence as long as they manage to remain wanted, e.g. the relationship between the product and its user stays strong enough (Schifferstein & Zwartkruis-Pelgrim, 2008; Mugge, 2007) to keep obsolescence at bay. According to the literature, emotional durability can either be achieved by designing products for *"attachment"* (Chapman, 2009, p. 33) so users feel a strong emotional connection to the product (Schifferstein, Mugge & Hekkert (2004), due to the service it provides, the information it contains, and the meaning it conveys, or by designing products for *"detachment"* (Chapman, 2009, p. 33) so users feel no emotional connection to the product, have low expectations, and thus perceive it in a favourable way due to a lack of emotional demand or expectation (Chapman, 2009). When the level of product attachment increases, the expected product lifetime, the level of product care and the notion of irreplaceability for a product all go up and the tendency to dispose of a product goes down (Mugge, 2007). Product attachment can occur at different levels (Mugge, 2007), varying from attachment to one particular product specimen to attachment to products in general, i.e., materialism. From this range, Mugge (2007) identified three levels for which the relationship between user and product can be considered to be a form of product attachment as defined by Schifferstein et al. (2004). These are attachment to a product specimen (i.e., one particular instance of a product), for example one's own car; attachment to a product variant (i.e., one specific type and model of product), for example a certain model of a car or attachment to a brand, for example the Citroën brand.

Despite of its recognized ability to induce obsolescence in functional products or overpower material causes of obsolescence, research into how industrial designers can design a potential for emotional durability into products has been limited. Chapman (2009) suggested *"this may be a consequence of the apparently intangible, ethereal nature of considerations pertaining to psychological function, which cause confusion for the practicing product designer tasked with the design and development of greater emotional longevity in products"* (p. 32). Page (2014) presented one of the most concise reviews to date of the literature on *"how consumer-product relationships are formed and whether these feelings influence replacement decisions"* (p. 265). Page's (2014) research makes clear that the field of product attachment is still under development, with different schools of thought that touch or overlap to a greater or lesser extent, but do not share a common structure or framework. The overall conclusion of the review presented by Page (2014) is that product attachment and emotional durability is influenced by many factors, some of which can be implemented and enhanced by designers. Many are, however, difficult to control. Page (2014) concludes: *"designers must think carefully about which attachment areas are appropriate to their product and consider their relevance for each consumer's situation"* (p. 280).

Physical Durability

Contrary to the concept of emotional durability, the concepts of physical durability and designing for physical durability have been researched quite extensively (see, e.g., Vezzoli & Manzini, 2008; Bijen, 2003; Keoleian & Menery, 1993).

With regard to the ability of a product to resist obsolescence, or to keep functioning over time, there are two key concepts in the literature that need to be discussed here: *reliability* and *durability*. Although the two concepts are related, they are not the same. By definition, reliability is expressed in relation to a specified period of time (Moss, 1985). Products that by design have a high level of reliability for a – sometimes short – period of time, such as condoms, single-use medical devices or single-use rocket boosters do not necessarily have a high level of durability. Conversely, products that by design have a high level of physical durability in many cases do exhibit a high level of reliability. In part, this is so because physical durability is often achieved by over-dimensioning and designing a product to higher specifications than would strictly be required for the product to function under normal operating conditions and in normal environments in order to be tolerant to wear and resistant to occasional abuse (e.g. use outside specified operating range) over time. In some cases, such as commercial aircraft, reliability and durability are highly interdependent and have thus become almost inseparable. Although reliability can be an important contributor to an extended product lifetime, as *"unreliable products or processes, even if they are durable, are often quickly retired"* (Keoleian & Menery, 1993, p. 67), the literature also contains evidence indicating that in some instances, reliability has limited or no effect on the onset of obsolescence. Schifferstein and Zwartkruis-Pelgrim (2008) for example observed that *"when a person becomes attached to an object, he or she is more likely to handle the object with care, repair it when it breaks down, and postpone its replacement as long as possible"* (p. 1) and Sung, Guo, Grinter and Christensen (2007) claimed that *"forming a strong bond with the technology is possible even in the face of technical issues, and further might lead people to persist in adoption despite problems"* (p. 157). We therefore consider durability, rather than reliability, the primary discriminating characteristic of design aimed at resisting obsolescence over time.

The literature refers to products that possess an innate resistance to obsolescence as *"durable items"* (Keoleian &Menery, 1993, p. 64) or as possessing durability (Bijen, 2003; Frohnsdorff & Masters, 1980) and contains several definitions for the concepts of durable and durability. Most of the descriptions agree that durability is about *"the possession of qualities associated with long-life"* (Frohnsdorff & Masters, 1980, p. 17) and *"staying strong and in good condition over a long period of time"* (Merriam-Webster, 2015a). In this thesis, we propose a new definition that is derived from the definition for durable items as provided by Keoleian and Menery (1993): *"durable items can withstand wear, stress and environmental degradation over a long useful life"* (p. 64) and the description of durability as provided by Bijen (2003). To better reflect that physical durability is a material quality of a product and to better distinguish it from the concept of emotional durability presented above this newly synthesized definition adds the term physical to durability:

Physical durability is the ability of products to withstand wear, stress, and environmental degradation and remain able to fulfil all physical functions for which it was designed over a long period of time.

A product has a high physical durability if its performance over time degrades slower than comparable products on the market. Degradation can, for instance, be caused by wear, fatigue, creep, and corrosion and can, to a certain extent, be influenced by the design of the product and its components (Bijen 2003; Goel & Singh, 1997; Keoleian & Menery, 1993; Frohnsdorf & Masters, 1980).

2.5.2 Postponing Obsolescence: Designing for Maintenance, Repair and Upgrading

Maintenance

The international standard EN 13306 (EN, C., 2010) on maintenance terminology defines maintenance as the *"combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function"* (p. 5). In this definition, postponing obsolescence (i.e., retaining a product in a functioning state) and reversing obsolescence (i.e., restoring a product to a functioning state) are both considered maintenance. In practice, this led to the terms preventative (and predictive) maintenance (retaining) and corrective maintenance (restoring) being introduced (Moss, 1985). In the typology presented in figure 2.5.2, designing for maintenance is used as preventative (and predictive) maintenance and not as corrective maintenance. Maintenance terminology was developed in the field of engineering, which is why (according to the standard definition) it focuses on technical and organizational issues. In addition to making adjustments to the settings of the original product, maintenance removes elements that are foreign to the original product, for example dust, and/or adds or replaces specific elements (consumables) that are required for the standard operation of the (durable) product, for example, fuel, filters, or lubricants. These maintenance activities are often characterized by their repetitive nature. When applied to consumer products, maintenance retains an aesthetic and/or hygienic condition, like in clothes laundering (washing and ironing). This is captured in the following definition:

Maintenance is the performance of inspection and/or servicing tasks at regular intervals, to retain a product's functional capabilities and/or cosmetic condition.

Repair

In a context where products are used as capital goods (e.g., manufacturing), repair is usually equated with the term corrective maintenance (Moss, 1985). As the focus of the thesis is on durable consumer goods (see section sub-section 1.3.3 Scope), however, we propose to use the term repair as it is more familiar to consumers. This study uses a definition of repair based on Ijomah et al. (2004), but with the inclusion of a statement about the end condition of the product, as introduced by Stahel (2010) and Flexner (1987) in their definitions of repair. Also, as the adjectives *sound* and *good* in Flexner's (1987) definition are open to multiple interpretations, they were replaced by *working*. A statement regarding warranty is further included here as Ijomah et al. (2004) found that when a product's obsolescence is reversed, *"a warranty serves as a guide to a product's quality"* (p. 6). Given that manufacturers may expand their warranty coverage as part of a marketing strategy, the included statement represents the minimum warranty coverage associated with each particular type of intervention.

Repair is the correction of specific faults in an obsolete product, bringing the product back to working condition, whereby any warranty on the repaired product generally is less than those of newly manufactured equivalents and may not cover the whole product, but only the component that has been replaced.

Upgrading

The definition of upgrading is an extension of the above definition of maintenance, whereby *retain* is replaced by *enhance* to express the overall intent of the process of upgrading, as defined by Flexner (1987), cited in Linton and Jayaraman (2005):

Upgrading is the process of enhancing, relative to the original design specifications, a product's functional capabilities and/or cosmetic condition.

Upgrading is usually done when a product is still in good working order, but the context of use changes, making it necessary to enhance the product's capabilities. As the user of a pair of sturdy leather boots grows older (i.e., changing context of use), feet may require more support. Upgrading the boots by fitting orthotics prolongs the boots' use cycle and extends their lifetime.

2.5.3 Reversing Obsolescence: Designing for Recontextualizing, Refurbishing, and Remanufacturing

This section describes and defines four design approaches aimed at reversing obsolescence (e.g., recovery) at product level, ordered by declining product integrity: design for recontextualizing; repair; refurbishing; and remanufacturing.

Recontextualizing

Recontextualizing is a new term, which was introduced to replace the term repurposing. From the current literature (EMF, 2014; BSI, 2009, 2011; EC, 2008; Oakdene Hollins Ltd., 2007; Watson 2008; Gray & Charter 2007), it is unclear whether or not repurposing, defined in BS 8887-2:2009 (BSI, 2009) as *"utilize a product or its components in a role that it was not originally designed to perform"* (p. 5) allows for remedial actions. In addition to these changes in role, repurposing can also denote changes in user or owner (person or organization) (Oakdene Hollins Ltd, 2007). This is, however, not evident from its current definition, that further fails to explicitly accommodate for changes in the wider context surrounding the product, like, for example, business model and/or regulatory framework. In our definition of the proposed new term recontextualizing, all changes to factors *other than the tangible product as it was at the moment it became obsolete* are considered changes in context. Remedial actions, like repair, are explicitly excluded to prevent overlap with other recovery interventions. Examples of recontextualizing are the second-hand sales of a pair of sturdy leather boots (change of owner), the deployment of an older laptop computer as a thin-client server (change of role), and the use of older and previously privately-owned cars as cheap rentals. We propose the definition below:

Recontextualizing is a term for use of an obsolete product (or its constituent components), without any remedial action, in a different context than it was used in as it became obsolete.

Refurbishing

In figure 2.5.2, refurbishing or reconditioning is placed in the column to the right of repair and above remanufacturing. The reason for this, as Oakdene Hollins Ltd. (2007) argued, is that *"unlike remanufacturing, reconditioning only requires the rebuilding of major components to a working order rather than 'as-new'; yet, unlike repair, all major components that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components"* (p. 20). Similar to repaired products, however, *"reconditioned products tend to have a lower performance specification and associated warranty than the equivalent new product"* (Oakdene Hollins Ltd., 2007, p. 20).

In the newly synthesized definition of refurbishing, we introduce a cosmetic aspect, clearly distinguishing it from repair not only by the extent, but also by the nature of interventions:

Refurbishing, or its equivalent reconditioning, is the process of returning an obsolete product to a satisfactory working and/or cosmetic condition, that may be inferior to the original specification, by repairing, replacing or refinishing all major components that are markedly damaged, have failed, or that are on the point of failure, even where the customer has not reported or noticed faults in those components. Generally, any warranty on a refurbished product applies to all major wearing parts but is less than that of a newly manufactured equivalent.

As the thesis considers refurbishing in the context of durable consumer goods, it is considered an intervention for reversing obsolescence.

Remanufacturing

Remanufacturing is often taken to be an equivalent, or a variety, of refurbishing. This thesis, however, argues that the two are not the same. The differences originate in the way they deal with issues concerning brand and (control of) intellectual property. Whereas brand and (control of access to) intellectual property play an important role in business and industrial design, the current definitions of remanufacturing focus on functional aspects and are not explicit with regard to the actors that can engage in manufacturing (BSI, 2009; Oakdene Hollins Ltd., 2007; Sundin, 2004; Ijomah et al., 2004; Amezquita, Hammond, Salazar & Bras, 1995; Haynesworth & Lyons, 1987; Lund, 1983). We have therefore expanded the definition proposed by Ijomah et al. (2004) to incorporate the aspects of brand and (control of access to) intellectual property that set remanufacturing apart from refurbishing:

Remanufacturing is a term for a series of industrial processes in a factory environment, whereby an OEM (original equipment manufacturer), an OEM contracted third party, or a third party licensed to carry the OEM brand name, disassembles obsolete products into components, to a level as far down as needed to bring as many of those components as considered eligible after testing back to at least OEM original performance specifications and recombines those components—generally originating from different used products—with as few as possible new parts, to manufacture new products of a similar type and specification, that result in a new product with a warranty that is identical to that of an equivalent product manufactured out of all new parts.

The above definition is considered to build and expand on existing definitions of remanufacturing because it does not differentiate between remanufacturing and conventional manufacturing based on the end result but is based on the process followed in procuring raw materials and semi-finished products and in bringing the end result into being. It also includes an explicit statement as to the remanufacturing agent because active involvement of the OEM (Original Equipment Manufacturer) in remanufacturing efforts is considered essential. When there is no active involvement, as is the case with so-called independent or third-party remanufacturers (Jacobsson, 2000), it is highly unlikely that OEMs will make their intellectual property regarding product and process remanufacturing available to the level needed by third parties.

And, finally, the new definition does away with the distinction between a warranty on a product manufactured completely from new parts or a product manufactured from a combination of new parts and parts restored to at least OEM specifications as part of a remanufacturing process.

As the thesis considers remanufacturing in the context of durable consumer goods, it (in line with refurbishing) is considered an intervention for reversing obsolescence.

2.6 DISCUSSION AND CONCLUSIONS

In this chapter, we explored how the context of a circular economy (which is, in principle, an economy without waste) might affect the way we design products. The goal of the chapter was to provide a basis for the development of guiding principles, design strategies, and methods that could underpin product design for a circular economy, with tangible, durable consumer products as the focal point. Accepting that waste is not an option in a circular economy, we considered that prolonging and extending useful lifetime by preserving embedded economic value is the most effective way to preserve resources. This led to the redefinition of product lifetime and EoL (End of Life) in terms of obsolescence and to the introduction of the Inertia Principle and the concept of product integrity. By using the term obsolescence in the definitions of product use cycle and product lifetime, it was acknowledged that the duration of product use cycles and product lifetime are not solely determined by the physical properties of the isolated product, but rather by the perceived value within its wider context. Interventions to deliberately lengthen a product's overall lifetime can thus be aimed at modifying the physical properties of the product, as well as at altering the product's position relative to its wider context. The chapter presented a typology for design approaches for design for product integrity, which systematically describes different interventions for extending product lifetimes, classifying these as resisting, postponing, or reversing product obsolescence. Because the interventions are ordered according to the Inertia Principle, for example, decreasing ability to preserve product integrity, the typology helps to discriminate between the different options and provides initial guidance to industrial designers on how to prioritize the various interventions in their designs.

Subjectivity
It is, by definition, impossible to objectively state whether a product is obsolete or not. Subjectivity is at the heart of the definition of obsolescence and therefore at the heart of the definition of product lifetime. Obsolescence is largely in the eye of the beholder. It is, for example, often the user who determines whether or not a product is due for repair. A fully functional smart phone with a crack in the screen may be considered obsolete (and thus in need of immediate repair) by someone who highly values aesthetics, whereas it may seem in perfectly good working order to someone less concerned about the product's appearance. Even when the overall intention of *design for preserving product integrity* is clear, the subjective nature of obsolescence can make it difficult for designers to predict and determine the best design approach.

REFERENCES CHAPTER 2: PRESERVING PRODUCT INTEGRITY

Amezquita, T., Hammond, R., Salazar, M., & Bras, B. (1995, September). Characterizing the remanufacturability of engineering systems. In *ASME advances in design automation conference* (Vol. 82, pp. 271-278).
Bartels, B., Ermel, U., Sandborn, P., Pecht, M. (2012). *Strategies to the Prediction, Mitigation and Management of Product Obsolescence*. Hoboken, NJ, USA: John Wiley & Sons Inc.
Bayus, B. L. (1991). The consumer durable replacement buyer. *Journal of Marketing 55*(1), 42–51.
Behrens, A., Giljum, S., Kovanda, J., & Niza. S. (2007). The material basis of the global economy: Worldwide patterns of natural resource extraction and their implications for sustainable resource use policies. *Ecological Economics, 64*(2), 444–453.
Bijen, J. (2003). *Durability of engineering structures—Design, repair and maintenance*. Cambridge, UK: Woodhead.
Box, J. M. F. (1983). Extending product lifetime: Prospects and opportunities. *European Journal of Marketing, 17*(4), 34–49.
BSI (British Standards Institution) (2009). *BS 8887-2:2009. Design for manufacture, assembly, disassembly and end-of-life processing (MADE)*. Milton Keynes, UK: BSI.
BSI (2011). *PAS 141:2011. Reuse of used and waste electrical and electronic equipment (UEEE and WEEE). Process management. Specification*. Milton Keynes, UK: BSI.
Burns, B. (2010). Re-evaluating Obsolescence and Planning for It. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 39-60). Farnham, Surrey, UK: Gower Publishing Limited.
Chapman, J. (2005). *Emotionally Durable Design. Objects, Experiences, and Empathy*. London, UK: Earthscan.
Chapman, J. (2008). *Sustaining Relationships Between People and Things*. Retrieved November 20th, 2017 from http://eprints.brighton.ac.uk/6631/1/Sustaining_Relationships.doc.
Chapman, J. (2009). Design for (Emotional) Durability. Design Issues, 25(4), 29-35.
Ciacci, L., Reck, B. K., Nassar, N. T., & Graedel. T. E. (2015). Lost by Design. *Environmental Science & Technology 49*(16), 9443– 9451.
Cooper, T. (2010). The Significance of Product Longevity. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 3-36). Farnham, Surrey, UK: Gower Publishing Limited.
De Aguiar, J., De Oliveira, L., Da Silva, J. O., Bond, D., Scalice, R. K., & Becker, D. (2017). A design tool to diagnose product recyclability during product design phase. *Journal of Cleaner Production, 141*, 219–229.
Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology*, *21*(3), 517-525.
EC (European Commission) (2008). *Waste Framework Directive (2008/98/EC)* or *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives*. Retrieved October 30th, 2015 from http://eur-lex.europa.eu/legal- content/EN/TXT/?uri=CELEX:32008L0098.
EMF (Ellen MacArthur Foundation) (2014). *Towards the circular economy 3 - Accelerating the scale-up across global supply chains*. Retrieved October 30th, 2015 from www.ellenmacarthurfoundation.org/Publications.
EN, C. (2010). *13306: Maintenance - Maintenance terminology.*
Feldmann, K., & Sandborn, P. (2007). Integrating technology obsolescence considerations into product design planning. In *Proceedings of the ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2007*, 4–7 September, Las Vegas, NV, USA, 1–8.
Flexner, S. B. (1987). *The random house dictionary of the English language* (2nd ed.) New York, USA: Random House
Frohnsdorff, G., & Masters, L.W. (1980). The Meaning of Durability and Durability Prediction. In P.J. Sereda & G. G. Litvan (Eds.), *Durability of Building Materials and Components, ASTM (American Society for Testing and Materials) STP 691* (pp. 17-30).
Gharfalkar, M., Ali, Z. & Hillier, G. (2016). Clarifying the disagreements on various reuse options: Repair, recondition, refurbish and remanufacture. *Waste Management & Research, 34*(10), 995-1005.
Gray, C., & Charter, M. (2007). *Remanufacturing and product design: Designing for the 7th generation.* Farnham, UK: The Center for Sustainable Design University College for the Creative Arts. Retrieved September 4th, 2015 from http://cfsd.org.uk/Remanufacturing %20and%20Product% 20Design.pdf.
Goel, P. S., & Singh, N. (1997). A framework for integrating quality, reliability, and durability in product design with life-cycle cost considerations. *Quality Engineering, 10*(2): 267–281.
Graedel, T. E., Harper, E. M., Nassar, N. T., & Reck, B. K. (2015). On the materials basis of modern society. *Proceedings of the National Academy of Sciences*, *112*(20), 6295-6300.
Hagen-Zanker, J., & Mallett, R. (2013). *How to do a rigorous, evidence-focused literature review in international development, A Guidance Note*. London: Overseas Development Institute.
Hart, C. (2011). *Doing a literature review: Releasing the social science research imagination*. London, UK: SAGE.
Haynesworth, H., & Lyons, T. (1987). Remanufacturing by design: The missing link. *Production and Inventory Management, 28*(2): 24–29.
Ijomah, W. L., Childe, S., & McMahon, C. (2004). Remanufacturing: A key strategy for sustainable development. In *Proceedings of the 3rd International Conference on Design and Manufacture for Sustainable Development*, 1–2 September, Loughborough, UK. Retrieved April 20th, 2017 from www.researchgate.net/profile/Chris_Mcmahon3/publication/ 268411994_Remanufacturing_A_Key_Strategy_for_Sustainable_ Development/links/5554455f08ae6943a86f47cd.pdf.
Jacobsson, N. (2000). *Emerging product strategies—Selling services of remanufactured products*, Licentiate dissertation, The International Institute for Industrial Environmental Economics (IIIEE), Lund University, Lund, Sweden, ISBN 91-88902-17-X.
Keoleian, G. A., & Menerey, D. (1993). *Life cycle design guidance manual: Environmental requirements and the product system*. Document reference: EPA600/R-92/226. Ann Arbor, MI, USA: National Pollution Prevention Center, University of Michigan.
Kotler, P. (1984). *Marketing Management – Analysis, planning and control* (5th ed.), London, UK: Prentice/Hall International.
Linton, D., & V. Jayaraman (2005). A framework for identifying differences and similarities in the managerial competencies associated with different modes of product life extension. *International Journal of Production Research, 43*(9), 1807–1829.
Lund, R. T. (1983). *Remanufacturing: United States experience and implications for developing nations*. Cambridge, MA, USA: Center for Policy Alternatives, Massachusetts Institute of Technology.
Merriam-Webster (2015a). Definition of 'durable'. *Merriam-Webster online dictionary*, retrieved December 1st, 2015 from: www.merriam-webster.com/dictionary/durable.
Moss, M. A. (1985). *Designing for minimal maintenance expense: The practical application of reliability and maintainability*. Quality and Reliability series part 1. New York, NY, USA: Marcel Dekker.
Mugge, R. (2007). *Product Attachment* (Doctoral thesis). Delft University of Technology, Delft, the Netherlands.
Murakami, S., Oguchi, M., Tasaki, T., Daigo, I., & Hashimoto, S. (2010). Lifespan of commodities, part 1. The creation of a database and its review. *Journal of Industrial Ecology, 14*(4), 598–612.
Oakdene Hollins Ltd. (2007). *An Analysis of the Spectrum of Re-use*. Aylesbury, UK: Oakdene Hollins Limited. (Document reference: DEFR02 089 Reuse Review.doc).
Oswald, I. & Reller, A. (2011). E-waste: A story of trashing, trading, and valuable resources. *GAIA Ökologische Perspektiven für Wissenschaft und Gesellschaft, 20*(1), 41–47.
Page, T. (2014). Product attachment and replacement: Implications for sustainable design. *International Journal of Sustainable Design, 2*(3), 265–282.
Saddleback Leather Co. (2016). Saddleback Leather Co. company website: www.saddlebackleather.com.

Schifferstein, H. N. J., Mugge, R., & Hekkert, P. (2004). Designing Consumer-Product Attachment. In D. McDonagh, P. Hekkert, J. Van Erp & D. Gyi (Eds.), *Design and Emotion: The Experience of Everyday Things* (pp. 327-331). London, UK: Taylor & Francis.
Schifferstein, H. N. J., & Zwartkruis-Pelgrim, E. P. H. (2008). Consumer-Product Attachment: Measurement and Design Implications. *International Journal of Design, 2*(3), 1-13.
Stahel, W.R. (1986). Hidden Resources. Product Life as a Variable: The Notion of Utilization. *Science and Public Policy, 13*(4), 185-193.
Stahel, W. R. (2010). *The Performance Economy* (2nd ed.), Hampshire, UK: Palgrave Macmillan Hampshire.
Simões, C. & Dibb, S. (2001). Rethinking the brand concept: New brand orientation. *Corporate Communications: An International Journal, 6*(4), 217–224.
Sundin, E. (2004). *Product and process design for successful remanufacturing* (Doctoral dissertation). Linköping studies in Science and Technology, Linköping Institute of Technology, Linköping, Sweden.
Sung, J., Guo, L., Grinter, R. E., Christensen, H. I. (2007). My Roomba is Ramboo: Intimate Home Appliances. In J. Krumm, G. D. Abowd, A. Seneviratne, T. Stranget (Eds.), *Proceedings of UbiComp 2007* (pp. 145-162), Ubiquitous Computing, 9th International Conference, Innsbruck, Austria, September 16-19, 2007. Berlin Heidelberg, Germany: Springer Science & Business Media.
Tomczykowski, W. (2001). *DMSMS acquisition guidelines: Implementing Parts Obsolescence Management Contractual Requirements Rev. 3.0.* Defense Microelectronics Activity (DMEA). Contract reference DMEA90-00-F-0003. Retrieved October 30th, 2017 from www.dmea.osd.mil/ docs/acquisition_guidelines.pdf.
Van Ewijk, S., & Stegemann. J.A. (2014). Limitations of the waste hierarchy for achieving absolute reductions in material throughput. *Journal of Cleaner Production, 132*, 122–128.
Van Nes, N. (2003). Replacement of Durables: Influencing product life time through product design (Doctoral thesis, Erasmus University Rotterdam, Rotterdam, the Netherlands).
Van Nes, N., & Cramer, J. (2005). Influencing Product Lifetime through Product Design. *Business Strategy and the Environment 14*, 286-299.
Vezzoli, C. & Manzini, E. (2008). *Design for Environmental Sustainability*. London, UK: Springer-Verlag London Limited.
Watson, M. (2008). *A review of literature and research on public attitudes, perceptions and behaviour relating to remanufactured, repaired and reused products*. Aylesbury, UK: Center for Remanufacturing and Reuse. Retrieved September 4th, 2015 from www.remanufacturing.org.uk/pdf/story/1p143.pdf.

3

DESIGNING FOR PRESERVING PRODUCT INTEGRITY

What design interventions can industrial designers use when designing for long and extended product lifetimes in a circular economy?

3.1 INTRODUCTION

Chapter 3 aims to provide an answer sub-research question B: "What design interventions can industrial designers use when designing for long and extended product lifetimes in a circular economy?" Taking the typology presented at the end of chapter 2 as a starting point, the objective of chapter 3 is to bring the abstract design approaches for preserving product integrity from figure 2.5.2 to a more actionable level by identifying the design principles or *"laws, guidelines, human biases, and general design considerations"* (Lidwell, Holden & Butler, 2010, p. 12) that support the various design approaches for preserving product integrity and creating a typology for design strategies for preserving product integrity.

3.2 METHODOLOGY

Gathering Data

A literature review is done in order to identify design principles that can be applied in support of the design approaches for preserving product integrity from chapter 2. The review of the literature is based on the procedures described by Hagen-Zanker and Mallet (2013) as discussed in section 1.5 Research Design. The research presented in chapter 3 draws predominantly from scientific publications but also grey literature in the fields of eco-design, and (sustainable) product design. The initial body of literature, limited to documentary sources in the English, Dutch or German language but without limits to publication date, is compiled from the search results returned by Google Scholar, for search terms related to sustainable product design, eco-design, and circular economy. Building on the findings from chapter 2, the initial list of search terms consists of (combinations of): "product design," "recondition*," "recover*," "refurbish*," "remanufactur*," "recycl*," "reuse," "repair," "upgrad*. Using snowballing, new keywords that emerge are added to the initial set.

The results of the searches were scan-read to determine, based on the over 20 years of hands-on experience of the author in the fields of commercial industrial design and sustainable design and erring on the side of caution, whether they pertained to product design, product design for extended lifetimes, product lifetime, circular economy, sustainability and business in a manner that was potentially relevant to the topic of the research. Clearly irrelevant results, for example highly technical econometric or computing related papers, were discarded before storing the results in a software-based retrieval system and assigning (additional) keywords to them for later reference.

In total, over 150 articles are studied in detail in order to gain a deeper understanding, identify the *seed literature* (works of research on the topic considered as fundamental in the specific field) and to detect similarities, discrepancies, inconsistencies, and/or contradictions (Hart 2011).

Processing and Analysing Data

For each of the design approaches from the typology presented in figure 2.5.2 we collected from the literature the (descriptions of) design principles that support them, with the aim of establishing unique sets of design principles that each would characterize a particular approach, thereby turning it into an actionable design strategy for preserving product integrity. As different authors used different phrasing for highly similar or identical design considerations and interventions, descriptions of highly similar or identical interventions were first brought together under a single heading. Descriptions of proposed design interventions such as *"improve product labelling"* (CRR, 2009, p. 27) and utilizing *"engraving, marking, or labelling for quick location of parts or assemblies"* (Moss, 1985, p. 38) were combined into the single design principle of identification. Next, a table was constructed to create an overview of the eight design approaches from the typology for figure 2.5.2 with the design principles (including descriptions) that supported them. Because of the virtually complete overlap in design principles between the different design approaches that was found (and their resulting lack of discriminative power), we revisited the literature with the aim of identifying additional factors that could be used to discriminate (and hence provide guidance to industrial designers) between the different design approaches.

3.3 DESIGNING FOR RESISTING OBSOLESCENCE: A REVIEW OF THE LITERATURE

In this section, we will present the design interventions for the various approaches for designing for resisting obsolescence that are present in the current literature.

3.3.1 Design Principles for Emotional durability

A product has a high emotional durability if it remains wanted by users longer than comparable products on the market (see sub-section 2.5.1).
Page (2014), in the review mentioned earlier in sub-section 2.5.1, found that the current literature on emotional durability is scant and inconclusive as to how product attachment can be achieved by design:

> there are many determinants and influential factors of product attachment; some can be implemented and enhanced by designers, however many are difficult to control. The unreliable nature of the topic means that there is not one specific theme of attachment that is more prominent that others, instead designers must think carefully about which attachment areas are appropriate to their product and consider their relevance for each consumer's situation (p. 280).

Of the limited amount of research into emotional durability that has been conducted, much has been focused on (how to achieve) product attachment, i.e., the emotional bond with a specific product as experienced by a user (Schifferstein et al., 2004) in one-on-one relationships between an individual product and its user (Page, 2014; Grosse-Herring et al., 2013; Chapman, 2009, Schifferstein & Zwartkruis-Pelgrim, 2008; Van Nes, 2003; Mugge, 2007). The literature, however, provides virtually no information as to how to achieve the detachment.

This section provides an overview of the design principles from the present literature that industrial designers can apply to design a potential for emotional durability through attachment into their products.

Some of the design principles for achieving product attachment from the current literature focus on the material aspects of tangible products. Industrial designers can for example prepare a product for emotional durability by exercising stylistic restraint and craft the design of a product in such a way that it will remain *"in general fashion acceptance"* (Mugge, 2007, p. 91) over time, i.e., possesses an aesthetic quality that is perceived as timeless. Chapman (2009) and Van Hinte (1997) suggested choosing materials for products that tend to deform and age with grace, so that *"the signs of wear and tear are interpreted positively by the consumer"* (Mugge, 2007, p. 114), allowing products to *"'age with dignity' to stimulate product attachment"* (Mugge, 2007, p. 140) and develop *"a tangible character through time, use and sometimes misuse"* (Chapman, 2009, p. 33). According to Mugge (2007), carefully choosing product shape, material and colour can help turn products into means of *"self-expression"* (Mugge, 2007, p. 29), thereby facilitating the emergence of an emotional bond between the product and the user.

Other design principles for achieving product attachment are aimed more directly at affecting (the quality of) the interaction between the product and its user. Industrial designers can for example attempt to evoke product attachment by allowing for a product to be personalized by its user, either for functional or aesthetic purposes (Mugge, 2007; Piller & Müller, 2004; Blom & Monk, 2003; Fox 2001) or by designing products in such a way that the personality of the product matches the personality of the user (Mugge, 2007).

Chapman (2009) proposed that product attachment could be fostered by designing products in such a way that they exhibit some form of *"consciousness"* (p. 33). Designers can for example design a product to look, move and behave as if it is alive (Chandler & Schwartz, 2010; Mullaney, 2010; Scholl & Tremoulet, 2000; Heider & Simmel, 1944) and *"autonomous and in possession of its own free will"* (Chapman, 2009, p. 33), or even have it demand regular attention from its user in order to stay 'alive' (Chapman, 2005) as was for example done with the Tamagotchi toy (Bandai, 2017), a virtual, digital pet that needed to be cherished and fed by its user. Designing products that are seemingly in possession of their own free will and acting autonomously is also known in the literature as *designing for animacy* (e.g. Bartneck, Kulić, Croft & Zoghbi, 2009), i.e., the quality of condition of being alive (Oxford Dictionaries, 2015). When designing for animacy, industrial designers can try to entice users to engage in an emotional relationship with a product by designing the product a way that helps users to *zoomorphize* (*i.e.,* attribute animal traits to human beings, deities, or inanimate objects (VandenBos, 2007)) or *anthropomorphize* (*i.e.,* attribute human characteristics to nonhuman entities (VandenBos, 2007)) the product (Tokaya, 2013). Designers can for example make products respond to their environments (Mullaney, 2010), use human or animal like behaviour patterns (Heider & Simmel, 1944) and/or rhythms that are typical to living creatures, like reflexes, heart rate or breathing. The latter has for example been applied by the North American computer company Apple (2017a) in some of their laptop computers: Their standby lights blinked with exactly 12 cycles per minute, where the average respiratory rate of an adult is between 12-20 breaths per minute (Macnn, 2010).

Grosse-Hering et al. (2013) applied the principles of Slow Design or Design for Mindfulness and Consciousness to stimulate *"mindfulness"* (Grosse-Hering et al., 2013, p. 3439) in the user when interacting with the product. The seven principles of Slow Design are: 1) Reveal (i.e., creating awareness, uncover the function and essence of a product), 2) Expand (i.e., give a bigger picture: zoom in (what is it made of?) and zoom out (where does it come from?), 3) Reflect (i.e., provide time for the user to think and reflect about his or her actions, visualize processes and create narrative products), 4) Engage (i.e., do-it-yourself concepts; the user becomes a designer; the user is active in the creation of the product), 5) Participate (i.e., create opportunities, supporting the user to personalize and reconfigure the product; the user is active during the use of the product), 6) Evolve (i.e., create products that are changing or

3

growing over time) and 7) Ritual (i.e., create rituals for a better user experience, stimulating social interaction and provide security and stability in a hectic society) (Grosse-Hering et al., 2013). Based on the results of their case study (using a healthy juicer as design case) arrived at the conclusion that the principles of Design for Mindfulness and Consciousness

> can be interpreted by designers and indeed be applied to a mass-produced product. In conjunction with literature and this research there are early indications that show Slow Design has the potential to strengthen product attachment when applied with consideration. Slowing products and people down needs to be done at the right time and only then will a more mindful interaction occur that can support the product attachment theories (p. 3439).

Page (2014) expanded on the findings from the existing literature by proposing to design products for attachment by designing them in such a way that they inspire trust. Trust is an important prerequisite for the development of any kind of relationship (Young, 2006). Inspiring trust, however, is complex, as it is neither a behaviour, nor a choice (Egan, 2011). It is also not a single emotion (Young, 2006). The Merriam-Webster dictionary defines the concept of trust as *"assured reliance on the character, ability, strength, or truth of someone or something"* (Merriam-Webster, 2015b). Over time, products can evoke this psychological state of assured reliance by behaving as expected, e.g., not breaking down unexpectedly and keeping on functioning in a reliable manner. This particular avenue for getting to a long-lasting relationship between user and product may potentially provide an explanation for Mugge's (2007) finding that *"consumers may keep certain products for a long time, although they may not feel attached to them"* (p. 20), i.e., for those long-lasting relationships that are not based on an emotional bond. These relationships are perhaps instigated by rational calculation, only to evolve into combination of ratio and emotion later on.

An overview of the design principles for emotional durability that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

3.3.2 Design Principles for Physical Durability

A product has a high physical durability if its performance over time degrades slower than comparable products on the market (see sub-section 2.5.1). The literature suggests that to increase the potential for physical durability in a product, industrial designers could begin with selecting a basic conceptual operating principle for performing a specific function that reduces the number of (moving) parts required for performing that particular function, thereby maximizing the simplicity and the robustness of the operating principle (CRR, 2009; Vezzoli & Manzini, 2008; Bijen, 2003 Keoleian & Menery, 1993). Compare for example the difference in complexity (and thus potential problems) in the design solutions for keeping time of a clockwork, an hourglass or a sundial. Next, industrial designers could detail the basic conceptual operating principle in a way that increases the resistance to wear or stress during the performance of a particular function (Vezzoli & Manzini, 2008; Bijen, 2003; Keoleian & Menery, 1993). Compare for example different types of movement, e.g., rotation versus translation, different types of connection, e.g., welding, bolting, gluing, snapping, pressing or stitching, or different production methods, e.g., casting, injection moulding, milling. When designing a product design, dimensioning parts so that the load on the part during use will under normal conditions never exceed the load that the material that a specific part is made of can handle, or over-dimensioning parts (i.e., adding a safety margin as is customary in safety critical products like aircraft) can help to further reduce stress during use (Bijen, 2003). In addition the literature suggests that careful matching of type and grade of components and materials with functional requirements and use environment can prevent chemical and/or mechanical and/or radiation and/or thermal degradation during the performance of a particular function (Vezzoli & Manzini, 2008; Bijen, 2003; Keoleian & Menery, 1993) as does the selection of the type of surface treatment to prevent chemical and/or mechanical and/or radiation and/or thermal degradation during the performance of a particular function (Bijen, 2003).

With regard to designing a potential for physical durability into products, Keoleian and Menery (1993), observed that *"some design actions may make a product more durable without the use of additional resources. However, enhanced durability may depend on increased resource use"* (p. 64). Keoleian and Menery (1993) therefore stressed that design interventions to increase physical durability should always be weighed against the (additional) resources required to achieve the increase in useful lifetime.

An overview of the design principles for physical durability that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

3.4 DESIGNING FOR POSTPONING OBSOLESCENCE: A REVIEW OF THE LITERATURE

In this section, we will present the design interventions for the various approaches for designing for postponing obsolescence that are present in the current literature.

3.4.1 Design Principles for Maintenance

Maintenance was defined in sub-section 2.5.2 as the performance of inspection and/or servicing tasks at regular intervals, to retain a product's functional capabilities and/or cosmetic condition. With regard to maintenance, Keoleian and Menery (1993) stated that *"the relative difficulty or time required to maintain a certain level of system performance determines whether that system can practically be maintained"* (p. 68). Designing for maintenance is thus to be interpreted as designing for maintainability, defined by Moss (1985) as *"that element of product design concerned with assuring that the ability of the product to perform satisfactorily can be sustained throughout its intended useful life span with minimum expenditure of money and effort"* (p. 35).

There is general agreement in the literature on designing for maintenance (e.g., Mulder, Blok, Hoekstra & Kokkeler, 2012; Vezzoli & Manzini, 2008; Kuo, Huang & Zhang, 2001; Keoleian & Menery, 1993; Moss, 1985) that product designers must strive to minimize downtime, ensure tool availability, factor in the resources and capabilities of the actor performing maintenance, minimize the complexity of required procedures, minimize potential for error; ensure accessibility to parts, components, or system to be maintained and minimize frequency of design-dictated maintenance. Keoleian and Menery (1993) also advised that designers must be aware of the notion that *"most of these criteria are interrelated. If maintenance is complex, specialized personnel are required, downtime is likely to be long, and the potential for error increases. Specialty tools also make maintenance less convenient. Similarly, if parts or components are not readily accessible, complexity and cost can increase"* (p. 68) and emphasized that *"spatial arrangement is key to easy access. Critical parts and assemblies within a piece of equipment should be placed so they can be reached and the necessary procedures performed. Simpler designs are easier to maintain"* (p. 69). They furthermore noted that *"customers usually believe that the less often maintenance is required the better, so designs that preserve peak performance with minimal maintenance are likely to be more popular"* (Keoleian &Menery, 1993, p. 69).

With regard to maintenance and product lifetime, Keoleian and Menery (1993) stated that *"low maintenance designs are more likely to stay in service longer than less robust designs"* (p. 81). In addition, they remarked that *"products dependent on continual readjustments for an acceptable level of performance are generally considered low-quality"* (Keoleian &Menery, 1993, p. 81). The latter observation points towards a potential link between physical durability and emotional durability as products that are considered low-quality could be more prone to being discarded and becoming obsolete.

Moss (1985) identified and defined eight (design) principles in support of maintainability: 1) *"Standardization"* (p. 36), 2) *"Modularization"* (p. 36), 3) *"Functional packaging"* (p. 36), 4) *"Interchangeability"* (p. 37), 5) *"Accessibility"* (p. 37), 6) *"Malfunction Annunciation"* (p. 37), 7) *"Fault Isolation"* (p. 37) and 8) *"Identification"* (p. 38).

Standardization pertains to designing products and parts in such a way that they conform to *"generally accepted design standards for configuration, dimensional tolerances, performance ratings and other functional design attributes"* (Moss, 1985, p. 36). With regard to maintenance, the objectives of standardization are twofold (Moss, 1985). Firstly, standardization assures *"compatibility between mating parts"* (Moss, 1985, p. 36), for example when replacing an expendable unit, and between the product and the common tools, test equipment, and facilities used for its maintenance (Moss, 1985). Secondly, standardization helps to *"minimize the number of different spare parts that must be stocked for maintenance support"* (Moss, 1985, p. 36). With the design principle of modularization, a product is divided *"into multiple, smaller self-contained systems"* (Lidwell et al., 2003, p.136), that conform *"to dimensional standards based on modular "building block" units of standardized size, shape, and interface locations (i.e., locations for mating attachment or mounting points and input/output line connectors), in order to simplify maintenance tasks by enabling the use of standardized assembly/disassembly procedures"* (Moss, 1985, p. 36). The design principle of *"functional packaging locates all components ... performing a given function in ... a unit that is readily removable and replaceable as an entity)"* (Moss, 1985, p.36), allowing for example maintenance activities like cleaning or adjustment to be performed off-line. The objective of functional packaging is to expedite maintenance and reduce downtime (Moss, 1985). The design principle of *"interchangeability controls dimensional and functional tolerances of manufactured parts and assemblies to assure that* [a part that is expected to fail (or cause failure)] *soon can be replaced in the field with no physical rework required for achieving a physical fit, and with a minimum of adjustments needed for achieving proper functioning"* (Moss, 1985, p. 37). The design principle of *"accessibility controls the spatial arrangements of parts and assemblies within a piece of equipment so that each of these items is readily accessible"* (Moss, 1985, p. 37) for replacement, whereby *"evaluation of the relative accessibility of each component of a given design must take into consideration the physical limitations of the maintenance worker (human factors), and whether other items must first be removed in order to gain access to a specific item"* (Moss, 1985, p. 37). Malfunction annunciation serves to announce to the operator or user that a product is about to malfunction, especially *"in those cases where an* [approaching] *malfunction is not readily evident"* (Moss, 1985, p. 37). Moss (1985) provided the example of *"warning indicator lights on the dashboard of an automobile* [that] *are intended to alert you to approaching malfunctions in the engine cooling system, oil system, or electrical system so one can stop before losing power or damaging the engine"* (p. 37). The design principle of *"fault Isolation assures that an approaching equipment malfunction can be traced to the* [soon to be] *faulty part of the assembly requiring replacement, even if supplementary hardware must be provided solely for that purpose"* (Moss, 1985, p.37). The design principle of identification lastly, pertains to the utilization of *"engraving, marking, or labelling for quick location of parts or assemblies upon which preventive or predictive maintenance may have to be performed"* (Moss, 1985, p. 38).

The set of design for maintainability guidelines presented by Kuo et al. (2001) builds on the work of Moss (1985) and Keoleian and Menery (1993). However, it contains a number of additional design guidelines that were not mentioned – or not at that level of detail – by Moss (1985). Kuo et al. (2001) for example added the guideline that products need to be designed in such a way that injuries to those performing maintenance as well as damage to the product during maintenance activities (e.g., during disassembly and reassembly (Brennan, Gupta & Taleb, 1994)) are prevented. To achieve this, Kuo et al. (2001) suggested for example to leave sufficient space around components and to avoid sharp edges, corners and protrusions in the design. Furthermore Kuo et al. (2001) stated that the need for special tools must be minimized, to help ensure tool availability (Keoleian & Menery, 1993). To help speed up the maintenance process and avoid errors, Kuo et al. (2001) proposed to use *keying*, i.e., the use of matching geometric features (e.g., matching sizes and shapes like holes and pins) to ensure correct positioning of removable parts. The efficiency of maintenance activities can also be increased by locating part or units that require regular maintenance in such a manner that they can be accessed or removed with as little disturbance to the remainder of the product as possible, e.g., without having to first remove other parts or units and without interrupting critical functions (Kuo et al., 2001). In addition, Kuo et al. (2001) highlighted the importance of designing adjustments to function in line with what is commonly expected, e.g., clockwise, to the right, or up, to increase, and provided them with adequate end-stops to prevent damage. Lastly, Kuo et al. (2001) advised that heavy components or units should be placed as low as possible and be equipped with handles to facilitate their handling.

In addition to reiterating many of the guidelines discussed above, Vezzoli and Manzini (2008) in their guidelines for designing for maintenance cautioned designers to *"avoid narrow slits and holes to facilitate access for cleaning"* (p. 145). They furthermore suggested that designing for maintenance must *"pre-arrange and facilitate the substitution of short-lived components"* (Vezzoli & Manzini, 2008, p. 145) and aim for maintenance actions that could easily be performed onsite. Next to proposing that easily usable tools should be supplied with the product, they highlighted the importance of providing maintenance documentation (Vezzoli & Manzini, 2008).

Another set of guidelines for designing for maintenance was developed by Mulder et al. (2012). The set presented by Mulder et al. (2012) contains many of the guidelines presented earlier but is mentioned here as it adds several guidelines that were not discussed before. Mulder et al. (2012) advised to *"use materials that do not prolong maintenance activities"* (p. 15). This means for example avoiding the use of *"non-corrosion resistant materials in moist environments"* (Mulder et al., 2012, p. 15). Mulder et al. (2012) also suggested to *"use fasteners that accelerate maintenance activities"* (p. 19), and on this particular point went beyond

3

Moss (1985), Keoleian and Menery (1993) and Kuo et al. (2001) by adding that *"in the ideal situation, no tools are required to open or remove components"* (p. 19). In addition, Mulder et al. (2012) advised to position maintenance points in close proximity of one another and to ensure that *"the maintenance location is known beforehand"* (p. 39). In a central heating system for example, *"the active components ..., boiler and pumps, are located at one place"* (Mulder et al., 2012, p. 39).

The most notable new guideline proposed by Mulder et al. (2012) is to purposely *"design the weakest link"* (p. 35) for a product: An inexpensive part that is designed to wear out during use, thereby protecting parts that are more expensive and difficult to replace. Examples of such sacrificial parts would be the brake pads in the disc brakes of a car, that are designed to wear out many times faster than the actual brake discs (Mulder et al., 2012) or the magnesium blocks that are mounted on the hulls of steel ships to protect the hulls against the oxidizing effects of bronze propellers (Bijen, 2003).

An overview of the design principles for maintenance that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

3.4.2 Design Principles for Repair

Repair exchanges worn-out, damaged or broken parts from an obsolete product for other parts, either new or used, and/or adds matter that is foreign to the original product, for example glue, mechanical fasteners or filler metal (when welding) to restore a product to working order. As mentioned in sub-section 2.5.2, Moss (1985) considered repair a form of maintenance, calling it *corrective* maintenance. Although Moss' (1985) term for repair was not adopted by the thesis nor is always adopted elsewhere in the literature, there is general agreement in the literature that maintenance and repair are closely related. Keoleian and Menery (1993) for example stated *"factors relating to downtime, complexity, and accessibility are as important in repair as they are in maintenance. Easily repaired products also rely on interchangeable and standard parts"* (p. 81). Vezzoli and Manzini (2008) presented *"guidelines for reparation"* (p. 148) that were virtually identical to the ones they provided for maintenance. The Centre for Remanufacturing and Reuse (CRR, 2009) provided no design principles for maintenance or upgrading, but their guidelines for repair are virtually identical to those for maintenance and upgrading indicated by others: *"Improve product labelling"* (p. 27), *"specifying recyclable materials"* (p. 27), *"design for disassembly"* (p. 27), *"design components for durability"* (p. 27), *"design for easy cleaning and testing"* (p. 28), *"localise production and EoL treatment"* (p.28) and *"design for modularity"* (p. 28).

As there is general agreement in the literature that repair, maintenance and upgrading are closely related, we argue that the design principles from the literature that support the design approaches of designing for maintenance and designing for upgrading (see sub-sections 3.4.1 and 3.4.2) will also support the design approach of designing for repair.

An overview of the design principles for repair that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

3.4.3 Design Principles for Upgrading

Upgrading enhances the function of a non-obsolete product by replacing parts of a product that are not worn-out, damaged or broken by parts that have higher functional specifications than the original parts, for example exchanging the original working memory modules or the storage device in a computer for units with higher capacity or mounting parts with reduced weight as compared to the original parts on a sports bicycle. We consider upgrading an extension of maintenance (see sections 2.5.2 and 3.4.1). However, whereas maintenance often is characterized by repetitive activities, expendable filters for example are replaced regularly, a specific upgrade activity such as increasing computer RAM memory from 8 Gb to 16Gb, typically is only performed once on a particular product specimen over its entire lifetime.

Where Keoleian and Menery (1993) used the term *"adaptable"* (p. 66) to describe both *"designs that ... allow continual updating"* as well as designs that *"perform several different functions"* (p. 66), we propose here that adaptable products shall only be considered upgradable, if the new and different function was not part of the original design specifications.

Both adaptable and upgradable designs, like designs for maintenance, require interchangeable components (Keoleian & Menery, 1993). This implies that physical dimensions and geometry, but also data formats, on upgrades must be consistent with those of the original product in order to achieve compatibility (Keoleian & Menery, 1993). Although adaptability and upgradability can contribute to extending the useful lifetimes of products that otherwise would be prone to obsolescence, Keoleian and Menery (1993) emphasized that in order *"to reduce overall environmental impacts, a sufficient portion of the existing product must usually remain after obsolete parts are replaced"* (p. 66).

An overview of the design principles for upgrading that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

3.5 DESIGNING FOR REVERSING OBSOLESCENCE: A REVIEW OF THE LITERATURE

In this section, we will present the design interventions for the various approaches for designing for reversing obsolescence that are present in the current literature.

3.5.1 Design Principles for Recontextualizing

Recontextualizing reverses obsolescence by transferring an obsolete product, *without any changes to the tangible product as it was at the moment it became obsolete* to a new context that is different from the context the product was used in when it became obsolete and where the product is no longer considered obsolete (see sub-section 2.5.3). Successful reversal of obsolescence without any changes to the tangible product implies either that a product was fully functional and up-to-date when it became obsolete or that its new context does not require the (full) range of functions that the product was designed to perform (e.g., using the product for ornamental purposes (Aguirre, 2006)). As different contexts might pose different requirements, products that are adaptable and/or upgradable by design (Keoleian & Menery, 1993) can be at an advantage.

Products that are eligible for recontextualizing are therefore likely to have been designed with a potential for resisting obsolescence (i.e., physical and/or emotional durability), and/or for postponing obsolescence (i.e., maintenance and/or upgrading), and/or for reversing obsolescence (i.e., refurbishing, repair and/or remanufacturing). The concept of recontextualizing was newly introduced in this thesis. Specific research on design principles that support it therefore is not part of the present literature. Based on the above, however, we argue

3

that it is highly likely that recontextualizing is supported by the same design principles that support approaches for resisting, postponing and the remaining approaches for reversing obsolescence.

Tables 3.6.1 and 3.6.2 provide a complete overview of the design principles for recontextualizing that were identified from the current literature.

3.5.2 Design Principles for Refurbishing

Refurbishing combines the activities of maintenance with those of repair, whereby it expands the extent (but not the type) of the activities belonging to repair in two significant ways. First, with refurbishing "*all major components that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components*" (Oakdene Hollins Ltd., 2007, p. 20). Secondly it expands the activities belonging to repair to include not only the functional but also the *cosmetic* aspects of a product. As the type of activities remain the same, we argue that the design principles that support the design approaches of maintenance and repair (see sub-sections 3.4.1 and 3.5.2) are equally applicable to designing for refurbishing.

An overview of the design principles for refurbishing that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

3.5.3 Design Principles for Remanufacturing

Remanufacturing manufactures new products by (re)combining the parts from obsolete products with new parts. By definition (see sub-section 2.5.3) the identity of the original product is lost completely as a new product with a new identity is created in the process.

Whether or not a product can be successfully remanufactured by a manufacturer depends to a large extent on factors that lie outside the control of the domain of design (Sundin, 2004; Keoleian & Menery, 1993). To be viable as a commercial, industrial process, remanufacturing requires a sufficient population of old units (cores) that can be remanufactured (Sundin, 2004; Keoleian & Menery, 1993). Furthermore, collection of these cores requires the availability of a trade-in network and a storage and inventory infrastructure that can be operated at sufficiently low cost (Sundin, 2004; Keoleian & Menery, 1993). Lastly, remanufacturing can only be successful if there is a demand for products manufactured through a remanufacturing process (Geyer & Jackson, 2004, Sundin, 2004). Although in theory remanufacturing can be facilitating by either addressing the product design or the supply loop processes (Geyer & Jackson, 2004; Sundin, 2004), Amezquita and Bras (1996) found that an approach that integrates process and product design, however, is the most effective way to promote remanufacturing.

There are a number of aspects that affect the success and feasibility of remanufacturing that lie within the control of design and can be applied to enhance when designing for remanufacturing (Sundin, 2004). Product designed for remanufacturing must be easy to take apart and put together again (CRR, 2009, Sundin, 2004; Keoleian & Menery 1993), for the actual remanufacturing processes (e.g., inspection, cleaning, dis- and reassembly) as well as for efficient storage and transport (Sundin, 2004). The choice of connection types between parts is essential, as designs that make use of certain types of fasteners, adhesives or welding for example can hamper or even prohibit disassembly (Sundin, 2004). Products, parts and assemblies must be designed so they are easy to identify and handle (Sundin, 2004). They furthermore need to be designed in such a way that their (mal)functioning can be easily verified (Sundin, 2004). Vezzoli & Manzini (2008) proposed different design approaches for different types of parts, depending on their function. *"Expendable parts"* (Vezzoli & Manzini, 2008, p. 155) should be easy to remove and substitute. *"Structural parts"* (Vezzoli & Manzini, 2008, p. 155) should be designed in such a way that it is easy to separate them from *"external/visible* [parts]*"* (Vezzoli & Manzini, 2008, p. 155). Critical parts must be designed to survive normal wear in such a way that sufficient material remains present on used parts to allow refinishing after one or more use cycles (Vezzoli & Manzini, 2008; Sundin, 2004; Keoleian & Menery, 1993). Through material selection and consideration of the spatial arrangements (e.g., securing, nesting and stacking (Sundin, 2004) in light of collection processes, industrial designers can help prevent irreparable damage to parts during use, collection and transport (Sundin, 2004; Keoleian & Menery, 1993). By looking out to preserve *design continuity* (i.e., interchangeability of parts and components in a product line over time) in their designs, industrial designers can increase the number of interchangeable parts between different models in the same product line (Vezzoli & Manzini, 2008; Keoleian & Menery, 1993), making it easier to remanufacture products (Vezzoli & Manzini, 2008; Keoleian & Menery, 1993). Modularity can play an important role in this (CRR, 2009; Vezzoli & Manzini, 2008; Sundin, 2004; Kimura, 1997).

The design principles in support of remanufacturing suggested by the Centre for Remanufacturing and Reuse (CRR, 2009) consisted of all of their design principles for repair (see sub-section 3.5.2) with the addition of *"lightweighting"* (p. 28) and *"reducing the number of components"* (p. 28).

An overview of the design principles for remanufacturing that were identified from the current literature is presented in tables 3.6.1 and 3.6.2.

Designing for Preserving Product integrity

Design principle	*Description*
ACCESSIBILITY	Making "the spatial arrangements of parts and assemblies within a [product] so that each of these items is readily accessible for replacement or repair in-place" (Moss, 1985, p. 37).
ADAPTABILITY	Allowing a product to be continually updated (Keoleian & Menery, 1993) or to "perform several different functions" (Keoleian & Menery, 1993, p. 64). Updating allows a product to keep performing the functions it was originally designed for in a changing environment whereas upgrading enhances the functionality of a product.
ANIMACY	Making the product look, move and behave if it is alive (Chandler & Schwartz, 2010; Mullaney, 2010; Bartneck et al., 2009, Chapman, 2009; Heider & Simmel, 1944; Scholl & Tremoulet, 2000).
DIS- AND REASSEMBLY	Facilitating the process of removal of parts from and/or placement of parts in a product "while ensuring that there is no impairment of the parts [or product] due to the process. (Brennan et al. 1994, p. 59)
ERGONOMICS	"Designing and arranging things people use so that the people and things interact most efficiently and safely" (Merriam-Webster, 2016).
FAULT ISOLATION	Assuring "that an [approaching] equipment malfunction can be traced to the part of the assembly requiring replacement (Moss, 1985, p. 37).
FUNCTIONAL PACKAGING	Locating "all components ... performing a given function in ... a unit that is readily removable and replaceable as an entity)" (Moss, 1985, p.36).
IDENTIFICATION	Utilizing "engraving, marking, or labelling for quick location of parts or assemblies" (Moss, 1985, p. 38).
INTERCHANGEABILITY	"Controlling dimensional and functional tolerances of manufactured parts and assemblies to assure that [a part that is expected to fail or has failed] soon can be replaced in the field with no physical rework required for achieving a physical fit, and with a minimum of adjustments needed for achieving proper functioning" (Moss, 1985, p. 37)
KEYING	Utilizing matching geometric features (e.g., matching sizes and shapes like holes and pins to ensuring correct positioning of connectors, components and parts. (Kuo et al., 2001).

Table 3.6.1 : Overview of design principles for preserving product integrity as present in the literature.

Design principle	*Description*
MALFUNCTION ANNUNCIATION	Providing means "for indicating to the operator that the equipment is malfunctioning, in those cases where a malfunction is not readily evident" (Moss, 1985, p. 37).
MATERIAL SELECTION	Selecting the material that is best suited to the design requirements of the product under consideration.
MODULARIZATION	Enforcing "conformance of assembly configurations to dimensional standards based on modular 'building block' units of standardized size, shape, and interface locations (e.g., locations for mating attachment or mounting points and input/output line connectors), in order to simplify maintenance tasks by enabling the use of standardized assembly/disassembly procedures" (Moss, 1985, p. 36).
OCKHAM'S RAZOR	"Given the choice between functionally equivalent designs, the simplest design should be selected" (Lidwell et al., 2003, p.142)
REDUNDANCY	Providing an excess of functionality and/or material in products or parts, for example to allow for normal wear or removal of material as part of a recovery intervention (Keoleian & Menery, 1993) or to prevent interruptions in the functioning of a product (Kuo et al., 2001)
SACRIFICIAL ELEMENTS	Introducing an inexpensive and easy to replace part that is "designed to be used up or destroyed in fulfilling a purpose or function" (Oxford, 2017), such as protecting more expensive and difficult to replace parts.
STANDARDIZATION	Enforcing "the conformance of commonly used parts and assemblies ... to generally accepted design standards for configuration, dimensional tolerances, performance ratings and other functional design attributes" (Moss, 1985, p. 36).
SURFACE TREATMENT SELECTION	Selecting the type of surface treatment (for example anodizing, painting, plating or coating (Bijen (2003)) best suited to the design requirements of the product under consideration.

Design principle	*Design direction* **Resisting obsolescence**		*Design direction* **Postponing obsolescence**			*Design direction* **Reversing obsolescence**		
	Design Approach **Designing for Emotional Durability**	*Design Approach* **Designing for Physical Durability**	*Design Approach* **Designing for Maintenance**	*Design Approach* **Designing for Repair**	*Design Approach* **Designing for Upgrading**	*Design Approach* **Designing for Recontex-tualizing**	*Design Approach* **Designing for Refurbishing**	*Design Approach* **Designing for Remanu-facturing**
ACCESSIBILITY			• 1, 2, 4, 7, 9	• 1, 2, 4, 7, 15	• 16	• 17	• 18	• 5, 7
ADAPTABILITY	• 11		• 1, 2, 9	• 2, 15	• 16	• 17	• 18	• 5, 6
ANIMACY	• 13							
DIS- AND REASSEMBLY			• 1, 2, 3, 4, 7, 9	• 1, 2, 4, 7, 8, 15	• 16	• 17	• 18	• 3, 5, 7, 8
ERGONOMICS			• 1, 2, 4, 7, 9	• 1, 2, 4, 7, 15	• 16	• 17	• 18	• 5
FAULT ISOLATION			• 1, 2, 4, 9	• 1, 7, 15	• 16	• 17	• 18	• 5
FUNCTIONAL PACKAGING			• 1, 4, 7, 9	• 1, 15	• 16	• 17	• 18	• 5, 7
IDENTIFICATION			• 1, 4, 9	• 1, 8, 15	• 16	• 17	• 18	• 5, 8
INTERCHANGEABILITY			• 1, 2, 4, 7, 9	• 1, 15	• 16	• 17	• 18	• 2, 5, 6
KEYING			• 4, 9	• 15	• 16	• 17	• 18	• 5
MALFUNCTION ANNUNCIATION			• 1, 7, 9	• 1, 7, 15	• 16	• 17	• 18	• 5
MATERIAL SELECTION	• 10, 11, 13	• 2, 7, 12	• 9	• 15	• 16	• 17	• 18	• 5, 8
MODULARIZATION			• 1, 4, 7, 9	• 1, 8, 15	• 16	• 17	• 18	• 5, 7, 8, 14
OCKHAM'S RAZOR	• 10, 13	• 2, 7, 8, 12	• 2, 7	• 15	• 16	• 17	• 18	• 8
REDUNDANCY	• 10, 13	• 7, 12	• 1, 2, 4	• 2, 15	• 16	• 17	• 18	• 2, 5, 7
SACRIFICIAL ELEMENTS			• 9				• 18	• 7
STANDARDIZATION			• 1, 2, 4, 9	• 1, 2, 7, 15	• 16	• 17	• 18	• 2, 5
SURFACE TREATMENT SELECTION	• 11	• 2, 7, 12	• 4, 9	• 8, 15	• 16	• 17	• 18	• 5, 7

Table 3.6.2 : Overview of design principles, design directions and design approaches for preserving product integrity as present in the literature.

Notes: 1 = Moss (1985), 2 = Keoleian and Menery (1993), 3 = Brennan et al. 1994, 4 = Kuo (2001), 5 = Sundin (2004), 6 = Gray and Charter (2007), 7 = Vezzoli and Manzini, (2008), 8 = CRR, 2009, 9 = Mulder et al. (2012), 10 = Chapman (2009), 11 = Mugge (2007), 12 = Bijen (2003), 13 = Page (2014), 14 = Kimura (1997), 15 = design principles for maintenance support repair, 16 = design principles for maintenance also support upgrading, 17 = design principles for resisting and postponing obsolescence also support recontextualizing, 18 = design principles for maintenance and repair support refurbishing.

3.6 OVERVIEW OF DESIGN APPROACHES AND PRINCIPLES FOR PRESERVING PRODUCT INTEGRITY

Bringing together the design principles that support the various design approaches for preserving product integrity in one place, the summary of the review of the literature presented in table 3.6.1 visually underlines the insight gained from the literature that there is an almost complete overlap between the sets of design principles supporting the various design approaches for postponing and reversing obsolescence.

Although less visible in table 3.6.1, the literature review also showed that designing for emotional durability is closely connected with designing for physical durability, Chapman (2009) for example asserted that the way a product physically ages affects both its capacity for physical and emotional durability, and that designing for resisting obsolescence cannot be considered separately from designing for postponing and/or reversing objective obsolescence. Interventions for reversing obsolescence require a minimal amount of resistance to obsolescence to be present in a product. It is for example of no use to repair or remanufacture a product if nobody wants it anymore (i.e., a lack of emotional durability) Sundin (2004), or if all parts of a product are worn out or have broken to the extent that they all need to be replaced at the same time (i.e., a lack of physical durability). Page (2014) concluded that the ability of products to remain wanted was determined by *"their functionality and usability"* (p. 266) as well as by *"the sentimental affection and personal meaning they have to the user"* (p. 266), and next to trust named product qualities as reliability, durability and pleasure of use as important contributors to emotional durability. This is in line with Mugge (2007), who stated *"a product's malfunctioning may elicit strong negative feelings, due to which premature detachment may take place"* (p. 20) and Keoleian and Menery's (1993) observation mentioned earlier that *"unreliable products or processes, even if they are durable, are often quickly retired"* (p. 67). Conversely, as reported by Mugge's (2007), an increase in product attachment, i.e., a resistance to obsolescence through emotional durability, leads to an increase in product care, i.e., postponing obsolescence through maintenance. Mugge's finding was reiterated by Schifferstein and Zwartkruis-Pelgrim (2008), who observed that *"when a person becomes attached to an object, he or she is more likely to handle the object with care, repair it when it breaks down, and postpone its replacement as long as possible"* (p. 1) In addition to this Sung, Guo, Grinter and Christensen (2007) claimed that *"forming a strong bond with the technology is possible even in the face of technical issues, and further might lead people to persist in adoption despite problems"* (p. 157). Keoleian and Menery (1993) noted that *"customers usually believe that the less often maintenance is required the better, so designs that preserve peak performance with minimal maintenance are likely to be more popular"* (p. REF). With regard to product lifetime potential Keoleian and Menery (1993) argued that *"low maintenance designs are more likely to stay in service longer than less robust designs"* (p. 81). They also pointed out another potential link between physical durability and emotional durability in observing that *"products dependent on continual readjustments for an acceptable level of performance are generally considered low-quality"* (p. 81) and therefore more prone to becoming obsolete (Keoleian & Menery, 1993).

There are two important consequences to the overlap discussed above. The first is that products designed to support one design direction will almost inevitably support, and often need to be designed to support one or more of the other design directions. The second is that design approaches cannot be distinguished solely on the basis of the design principles that support them.

3.7 A THREE-DIMENSIONAL DESIGN SPACE FOR PRESERVING PRODUCT INTEGRITY

3.7.1 A Three-Dimensional Design Space for Preserving Product Integrity: Concept

The notion that the three design directions of resisting obsolescence, postponing obsolescence and reversing obsolescence are in practice always intertwined, allows us to interpret the overall design intention for a particular product design for preserving product integrity as a function of the three theoretically independent design directions. As a result, we propose to visually represent the overall design intention for preserving product integrity of any product designed for preserving product integrity by plotting it in a three-dimensional design space. This visual representation of the relative importance of the three design directions within the overall design intention for products designed for preserving product integrity is intended to help industrial designers capture and better understand the potential for preserving product integrity as it was (or is to be (see section 6.4 A Framework for Managing Obsolescence)) designed into a particular product. The three-dimensional design space for preserving product integrity provides industrial designers with a means to compare (and learn from) design intentions for different products, to recognize differences in emphasis on the various design directions between different (existing) products and to help steer the selection and interpretation of design principles for a particular product. An illustration of the three-dimensional design space for preserving product integrity shown in figure 3.7.1.

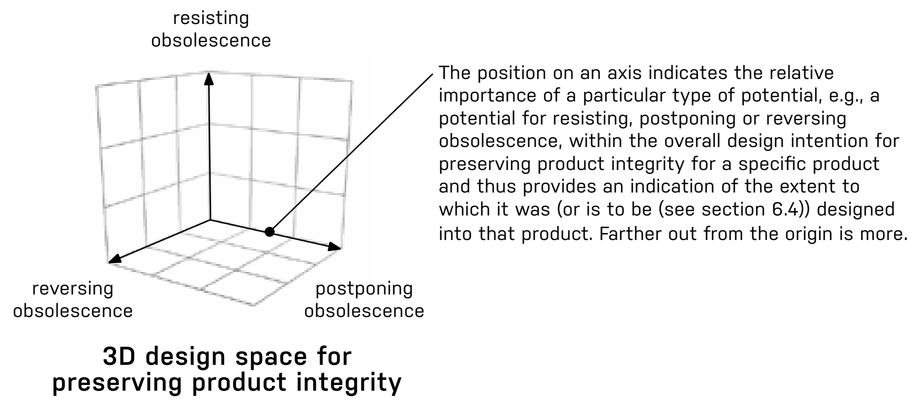


Figure 3.7.1: The three-dimensional representation of the design space for preserving product integrity.

The axes of the three-dimensional design space for preserving product integrity are each divided in three steps as this is the minimum number of steps that allows for a (non-equal) ranking of the importance of the three main design directions relative to one another, i.e., that allows for example for ranking the role of the design direction of postponing obsolescence above that of reversing obsolescence but below that of resisting obsolescence within the overall design intention for preserving product integrity of a particular product (see Loewe television diagram in figure 3.7.2).

3.7.2 A Three-Dimensional Design Space for Preserving Product Integrity: Mapping Example Products

In this sub-section, a number of example products is discussed briefly, and their positions are plotted accordingly in figure 3.7.2. The plotted representations of the composition of the overall design intention (and potential for preserving product integrity) in figure 3.7.2 are based on subjective, qualitative assessments based on the available information and could therefore differ depending on who is making the assessment. The purpose and significance of figure 3.7.2 for the thesis, however, does not lie in offering an absolute representation of the design directions used, but rather in demonstrating the workings of the concept of the three-dimensional design space for preserving product integrity and showing the considerable differences that exist between overall design intentions for different long-life products,

The Fairphone 2, Vitsoe 606 wall shelving, Saddleback Leather Co. leather bags examples are taken from the literature (e.g. Bakker, Den Hollander et al., 2014). The examples of Miele washing machines, Eastpak backpacks, Océ copiers, BMA Ergonomics office chairs, Loewe televisions and Tedrive steering units are based on company interviews that were conducted for the thesis and that will be presented in more detail in section 5.5.

Throwaway Products

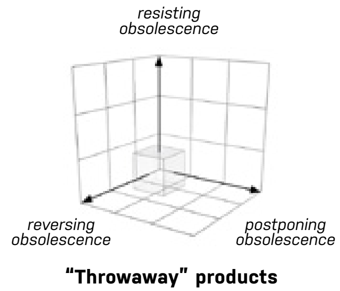
Products that have not been designed with preserving product integrity in mind, as unfortunately is the case with many products in today's throwaway society, populate only a tiny section of this three-dimensional design space, hovering closely around the origin. The area they occupy even protrudes beyond and below the origin of the three-dimensional design space for preserving product integrity as in the design of many of the current throwaway products preserving product integrity has not been considered at all or is actively obstructed (Schridde, 2014).

This narrow space occupied by throw-away products in general contrasts with the variety of positions occupied by different products that have been designed for long and extended product lifetimes, a few of which we will discuss below.

Fairphone 2

The Fairphone 2 (Fairphone, 2017) (see figure 3.7.3) is designed with the intention to last longer that the average phone by enabling the user to repair and upgrade the phone.

The typical useful lifetime of a smartphone currently is 2 years (Fairphone, 2017; Al-Jumeily, Hussain & Macilwee, 2014). The design intention for a Fairphone 2 is to extend that useful lifetime to a minimum of 5 years (Fairphone, 2017). Although a fair amount of physical durability is important, a projected lifespan of 5 years does not warrant nor requires the use of extremely wear and tear resistant materials and/or construction elements. Furthermore, the rate of change of technology used in smart phones tends to be high and the choice of materials (other than their sourcing) is dictated by the functional requirements of the electronic circuits. Based on this information, the design direction of postponing obsolescence (e.g., designing for upgrading and repair) is therefore ranked as of considerable higher importance in the design (Fairphone, 2017) than the design directions of resisting and reversing obsolescence. As such, the Fairphone 2 is plotted farthest out on the axis of postponing and a limited and equal distance out on axes of resisting and reversing obsolescence (see Fairphone 2 diagram in figure 3.7.2).



Three-Dimensional Design Space for Preserving Product Integrity:
- **The position of the cube** on an axis indicates the relative importance of a particular type of potential, e.g., a potential for resisting, postponing or reversing obsolescence, within the overall design intention for preserving product integrity for a specific product and thus provides an indication of the extent to which it was designed into that product. Farther out from the origin is more.
- **Resisting obsolescence:** designed for emotional and/or physical durability
- **Postponing obsolescence:** designed for maintenance and/or upgrading/and/or repair
- **Reversing obsolescence:** designed for recontextualizing and/or refurbishing and/or remanufacture

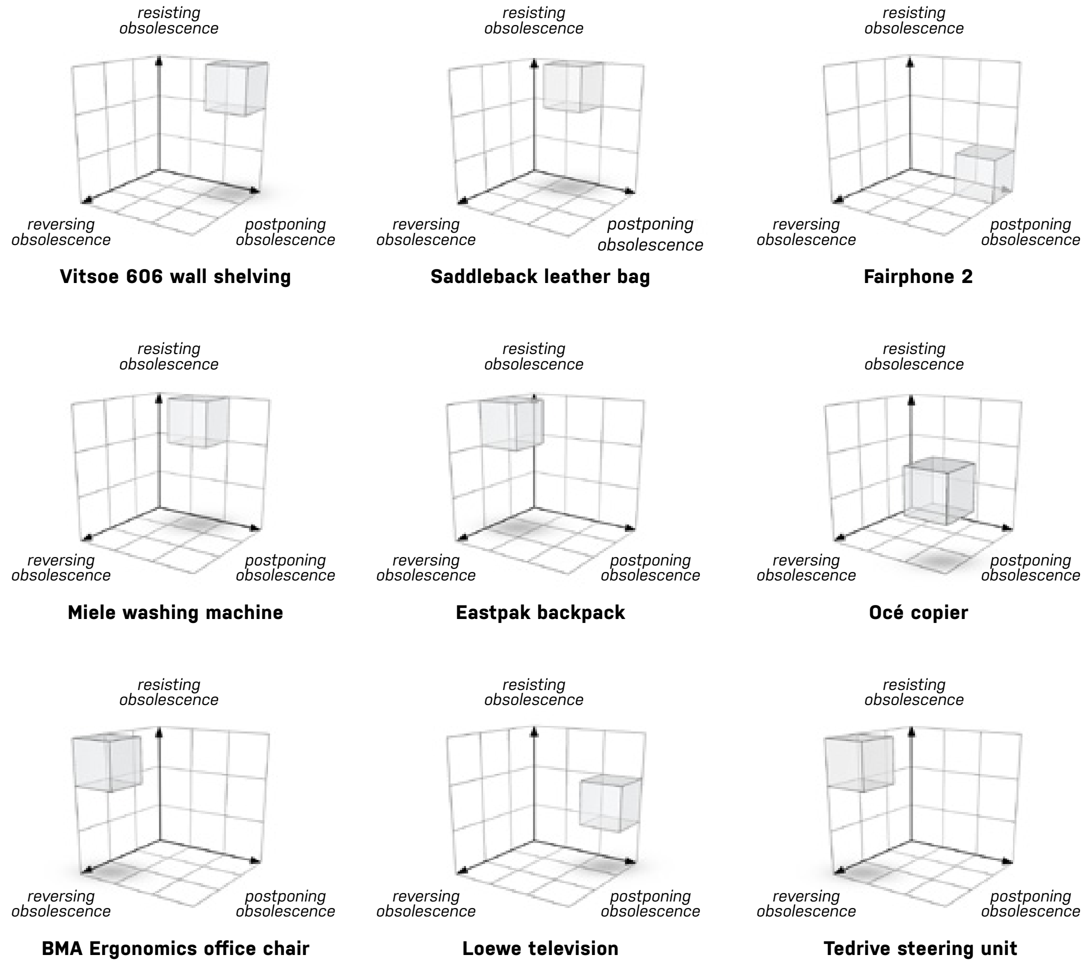


Figure 3.7.2: Example products plotted in the three-dimensional design space for preserving product integrity. The plotted representations of the composition of the overall design intention (and potential for preserving product integrity) are qualitative assessments based on the available information and can therefore differ slightly, depending on how the data is (subjectively) interpreted.

3

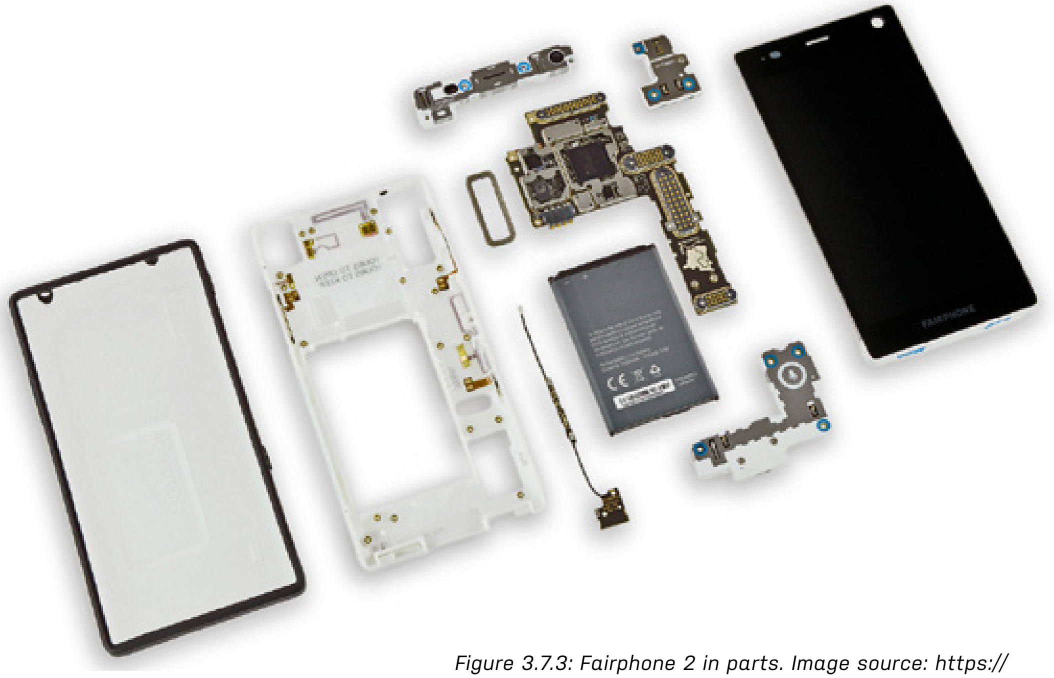


Figure 3.7.3: Fairphone 2 in parts. Image source: https://d3nevzfk7ii3be.cloudfront.net/igi/yXuyUATwQcmYlqlD.huge

Vitsoe 606 Wall Shelving

Vitsoe's 606 wall shelving system (Vitsoe, 2016) (see figure 3.7.4) was designed over 50 years ago by Dieter Rams (Vitsoe, 2016) as a system instilled with a potential to last (more than) a lifetime by being emotionally durable because of its stylistic restraint, physically durable because of its choice of materials and upgradable because of the standardisation of the connection interface, requiring virtually no repair. The system is updated and expanded from time to time with new components to meet present day requirements. All elements of the system that are bought today are designed and engineered to mix and match seamlessly with 50-year-old parts of the Vitsoe 606 system. Most of the components of the system are monolithic products (e.g., a metal arm or rail) that by their nature seldom require, and are unsuited for, repair. Individual components, however, can easily be exchanged should they break (Vitsoe, 2016). As such, the overall design intention for the Vitsoe 606 system is plotted high on both the resisting obsolescence axis and postponing obsolescence axis and low on the reversing obsolescence axis (see figure 3.7.2).

Saddleback Leather Co. Leather Bag

The leather bags from the North American Saddleback Leather Co. (Saddleback Leather Co., 2016) are designed with the intention to last long without repair and require minimal maintenance. (see figure 3.7.4). The bags are provided with a one-hundred-year warranty in North America. They are made out of high grade leather that can take substantial wear and tear and requires little to no maintenance. Fasteners and closures are simple in their operating principles (e.g., belts and clasps but no zippers) and mostly metal.

Figure 3.7.4: Vitsoe 606 universal wall shelving system. Image source: https://i.pinimg.com/originals/a7/f1/3a/a7f13a20d528799f67bc626146aa0848.jpg

The Saddleback Leather Co. designs remain (largely) unchanged over time and do not follow fashion trends. Should need be however, the way these bags are constructed ensures they can be repaired easily and with standard cobbler equipment and the choice of material, i.e., high grade, through and through coloured leather, ensures they can easily be cosmetically rejuvenated with a polish. The high grade of the workmanship, the materials selected and the one-hundred-year warranty all signal the bag was designed and built to last. To reflect this overall design intention, the Saddlebag leather bag is plotted high on the resisting obsolescence axis and halfway out on the postponing obsolescence axis (see figure 3.7.2).

Figure 3.7.5: Saddleback Leather Co. classic leather briefcase. Image source: http://images.saddlebackleather.com/image/upload/w_1280,h_1280,c_fill/SLCWeb/Products/01-10-0001/Rotator/LG-CH/f265f5.jpg

Miele Washing Machines

The washing machines of the German company Miele (Miele, 2017a) (see also interview results in sub-section 5.5.1) are designed to last 20 years without requiring much maintenance or upgrading, but to facilitate repair (preferably by Miele's own service technicians) if needed. In some of the Miele washing machines, the computer system managing the washing can be updated to better match new types of detergent (Vezzoli & Manzini, 2008). As such the design intention for a Miele washing machine is plotted high on the resisting obsolescence axis (e.g., designing for physical durability), a fair distance out on

3

the postponing obsolescence axis (designing for updating and designing for repair). As the Miele washing machines are not intended to be remanufactured and/or refurbished, they are plotted low on the axis for reversing obsolescence.

Eastpak Backpacks

Although Eastpak (2017) backpacks (see figure 3.7.6 and interview results in section 5.5.2) are considered lifestyle products, they are designed and manufactured to last. To underline their design intention, the Eastpak backpacks come with a lifelong (thirty-year in Europe) warranty on material and manufacturing defects.

The Eastpak backpacks are designed to be fashionable without being trendy and resist wear and tear, i.e., designed to resist obsolescence. The main compartment of the 'Padded Pak'r' backpack shown in figure 3.7.6 for example is made from a single piece of cloth that is put into its final shape with a single continuously stitched seam during manufacture, thus reducing the risk of seam failure during use (Eastpak interview, 2013, see sub-section 5.5.2). Because these are lifestyle items, the design of the Eastpak backpacks must strike a balance between being sufficiently stylish to be fashionable and being sufficiently neutral in order to not become obviously outmoded and have a long lifetime. As Eastpak has learned from experience and captured these learnings for educating their designers (Eastpak interview, 2013), many of their designs manage to embody this balance: The backpacks are assigned a different role over the course of their lifetime, i.e., are recontextualized, changing from book carrier to outdoor leisure daypack, as their owners move from school into their first jobs (Eastpak interview, 2013). Although these backpacks can be repaired, their design contains no special features to facilitate repair. The overall design intention for preserving product integrity of the Eastpak backpacks is therefore plotted high on the resisting obsolescence axis, halfway forward on the reversing obsolescence axis and low on the postponing obsolescence axis.

Figure 3.7.6: Eastpak Padded Pak'r backpack. Image source: https://shop.r10s.jp/sneaker-soko/cabinet/shohin001/bag0294.gif

Océ Copiers

Although not the actual copiers and printers, but rather service, paper and toner, are Océ's (2017a) primary source of revenue (see figure 3.7.7 and interview results in sub-section 5.5.4), Océ profits from longer copier and printer lifetimes as these allow Océ to supply service and consumables for longer and with fewer new machines.

Océ sell their copiers and printers to companies who in turn lease them out. In those instances where Océ manage to buy back the copiers and printers at the end of their use cycles, they remanufacture the equipment, so it can be leased out again for one or more new use cycles. As such, Océ design their copiers and printers in such a way that they can be maintained, updated and repaired efficiently (i.e., postponing obsolescence) and are suited for recontextualizing and remanufacture at the end of their use cycle(s) (i.e., reversing obsolescence). Extended physical durability (i.e., resisting obsolescence) is important for some components but less for others as during the remanufacturing process, copier and printer components are often upgraded to better match the current state of technology (see figure 3.7.2).

Figure 3.7.7: Océ VarioPrint 110. Image source: https://copiersonsale.com/wp-content/uploads/Oce-VarioPrint-110.jpg

BMA Ergonomics Office Chair

BMA Ergonomics (2017) (see figure 5.5.3 and interview results in section 5.5.3) design and manufacture their office chairs to embody BMA Ergonomics' ideas about how the human body can be optimally supported when doing seated work. As the human body changes little over time from a seating and support perspective, and BMA Ergonomics' office chairs are not fashion or lifestyle items, the design of the office chairs of BMA Ergonomics, built around a central and proprietary motion mechanism (BMA Ergonomics interview, 2012) changes little over time. The office chairs are designed and manufactured to last for multiple use cycles. With the exception of correcting occasional manufacturing defects, the BMA Ergonomics office chairs require little to no maintenance or repair over the course of their lifetime and as such require no special design measures to facilitate regular maintenance and/or repair. BMA Ergonomics aim to reclaim their office chairs after each use cycle (either through take-back agreements or lease contracts) and, after a quality and functionality check, make them available to another customer for a next use cycle, i.e., recontextualizes them. The overall design intention for BMA Ergonomics office chairs is therefore plotted high on the resisting and reversing obsolescence axes and low on the postponing obsolescence axis (see figure 3.7.2).

Loewe Televisions

Loewe designs and manufactures its premium television sets (see figure 3.7.8 and interview results in sub-section 5.5.6) to last longer than other television sets in the industry (Loewe, 2017). Loewe exercises stylistic restraint in their designs as to make the designs modern yet timeless and less sensitive to changing tastes (i.e., designed for resisting obsolescence).

Although the Loewe television sets are built to a high standard, Loewe keeps stock of spare parts for television sets up to seven years old to ensure their televisions can be repaired throughout their entire lifetime. The proprietary electronics in many of the Loewe television sets are designed in such a way that their functionality can be updated and upgraded by means of software (i.e., designed primarily for postponing obsolescence). The fast pace of technological change in the television product category as a whole (e.g. nobody wants to buy yesterday's technology at a premium), and the screen technology in particular (e.g. incompatible electronics), however, make it virtually impossible for Loewe to (design for) re-use any parts from obsolete products (Loewe interview, 2014) (see figure 3.7.2).

Figure 3.7.8: Loewe television set. Image source: https://www.loewe.tv/website/var/tmp/image-thumbnails/0/2872/thumb__third/loewe-fernseher-bild-7-oled-klang-5_tt.jpeg

Tedrive steering units

The unique and flexible way in which the Tedrive, now Knorr-Bremse (2017) (see figure 3.7.9 and interview results in sub-section 5.5.7) steering units for passenger cars and trucks are designed and manufactured, i.e., machines and welded from stainless steel tubing instead of cast in aluminium as is common in the industry, makes them ideally suited for use in vehicles produced in smaller series.

It also results in a housing that is much more resistant to pitting and corrosion that other steering systems in the market. As such, when remanufactured, these steering units are virtually indistinguishable from units manufactured from virgin materials. As each type of steering gear generally is developed for a particular make and model-year of vehicle, and models – as well as individual cars – have a limited lifetime, the time window during which remanufacturing is commercially viable is limited (Tedrive interview, 2014). During the course of a use cycle, however, these steering systems are maintenance free and seldom require

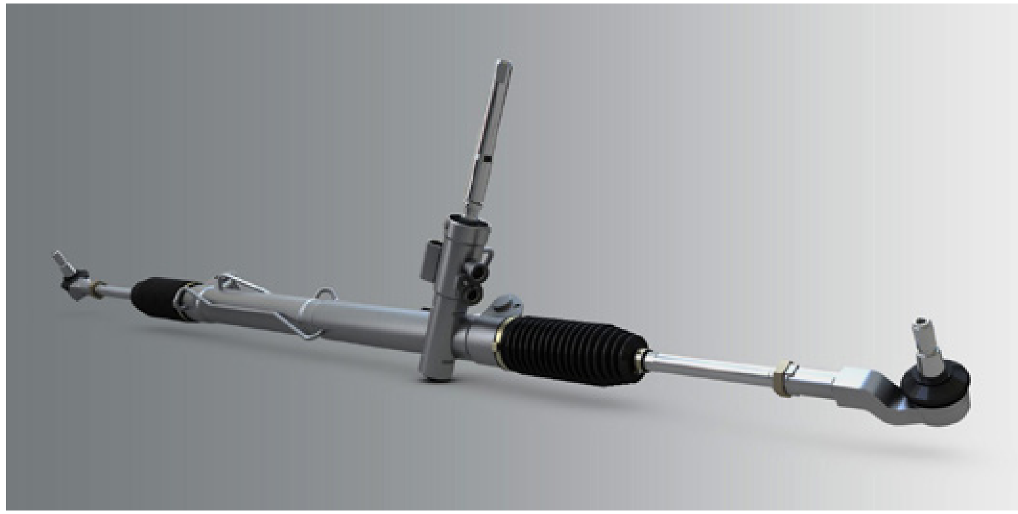


Figure 3.7.9: Tedrive hydraulic steering gear. Image source: http://www.rescoms.eu/assets/images/_bigImage/tedrive-hydraulic-steering-gear.jpg

repair. As such, the overall design intention for the Tedrive steering units is plotted far out on the resisting and reversing obsolescence axis and low on the postponing obsolescence axis (see figure 3.7.2).

3.8 DESIGN STRATEGIES FOR PRESERVING PRODUCT INTEGRITY

The observation that design principles by themselves are insufficient to discriminate between design approaches does not mean that all design approaches are the same. Design approaches can differ despite of this similarity in design principles used, because the design principles can be used in different combinations and with different design intentions. In the example of a car, the design principle of accessibility when used to support the design approach of designing for maintenance, would result in the filler caps for fuel, oil, coolant and wiper fluid to be within easy reach once the hood of the car has been opened. When used to support the design approach of designing for repair, the same design principle of accessibility would need to take into consideration the space a particular part needs to be able to pass through in order to be removed and reinstalled, and the clearance required for hands and wrenches to loosen and tighten nuts and bolts. When applying the design principle of identification for the design approach of repair, a part would most likely need to carry detailed information, most likely in the form of text and a barcode, that allows the part to be identified both as of the correct type (e.g. part number) and as a unique instance (e.g. serial number) in the logistic and administrative (e.g. warranty) process. A difference in colour, size and/or shape of the filler caps would, however, most likely be sufficient with regard to the application of the design principle of identification for the design approach of maintenance (e.g., the yellow, star-shaped, filler cap). The latter example illustrates how one design principle, in this instance the design principle of identification can interact with, or make use of, another design principle, in this instance the design principle of redundancy (colour *and* shape), in this instance both in support of the design approach designing for maintenance.

The particular mix of type of and intention for use of design principles is also influenced by the specific business-economic context of the product under consideration. This concerns for example who is doing the intervention and where it is done (e.g., the actor performing maintenance or repair (Keioleian & Menery, 1993; Moss, 1985). There is a difference in the way design principles are applied depending on whether a business wants an intervention to be performed by a layman consumer (e.g., self-maintenance or self-repair), by a specialized service technician (e.g. maintenance as a (paid) service, repair as a (paid) service or manual disassembly for remanufacturing) or by a dedicated robot (e.g. automated disassembly for remanufacturing). The business-economic context of the interventions can have consequences for parts, tools and information required to perform the interventions, as illustrated by the example below.

The Dutch manufacturer of mobile telephones Fairphone (Fairphone, 2017) for has designed their Fairphone 2 model so it can be easily upgraded and repaired by consumers. Repair instructions for example are imprinted in legible text upon many of the internal parts of the device.

North American Apple's iPhone 6 can be disassembled to the same level as the Fairphone 2, thereby also allowing for upgrades and repairs (iFixit, 2016a, 2016b). However, the iPhone uses proprietary screws and requires special tools in the process. Apple furthermore does not provide repair information as it wants to discourage updates and repair by independent repair shops and consumers.

These differences, however, do not necessarily mean that one approach is superior to the other from a designing for repair point of view.

The reason Apple uses the design principles for designing for repair in a different manner than Fairphone is that it has a different business philosophy than Fairphone. Apple prefers its service personnel, instead of users and independent repair shops, to perform upgrades and repairs.

Both Fairphone and Apple design their devices in accordance with their respective business philosophies. Fairphone supports product longevity by offering clear upgrade and repair instructions and replacement parts to their customers. Fairphone's strategy is aimed at fostering user-involvement and awareness and making the proper functioning of a Fairphone 2 a shared responsibility.

Apple does not provide hardware upgrades, but pledges to support it's the hardware and software for its devices for a period of five years after the product has been last manufactured (Apple, 2017b). Apple can do this because, by restricting consumer and independent repair shop access and modifications to their devices, they know the exact hardware configuration of every device they ever released (excluding those that against Apple's policy were modified by independent repair shops and consumers). Apple furthermore offers its 'AppleCare' (Apple, 2017c) program, a service contract providing extended warranty and technical support. In 2016, Apple articulated their particular vision on 'closing the loop' and manufacturer responsibility by presenting 'Liam', (Apple, 2016) a robot dedicated to the recovery of iPhones, claiming *"true innovation, means considering what happens to a product...at every stage of its lifecycle"* (Apple, 2016).

The consequences of the choices with regard to repair extend beyond the level of hardware design and technology. By emphasizing the capacity of the Fairphone 2 to be upgraded or repaired by the consumer, Fairphone has at the same time seems to have chosen to position its Fairphone 2 towards the 'smartphone as a powerful and modular tool for the technologically-inclined' end of the spectrum. In contrast, by shielding the consumer from the mundane, and to some daunting, realities of technology, Apple seems to have chosen to position its iPhone 6 towards the 'sophisticated and worry-free companion for the not-so-technologically-inclined' end.

Because Fairphone and Apple have such different business strategies with regard to extending product lifetimes, they are likely to have a different conception of what optimizing a design for repair (as well as other design approaches for extended product lifetime) should entail. With Fairphone, the design principles of accessibility and standardization are applied to designing for repair in such a way that they allow customers and independent repair shops full access to their product. With Apple, the same design principles are applied to designing for repair in a different way. There they are used to regulate access, e.g. restrict access to Apple authorized personnel. Despite their difference in business philosophy, both manufacturers appear to interpret the design principle of functional packaging as it applies to designing for repair in the same way, i.e., clustering components related to particular functions.

The purpose of the above example is to illustrate, reiterate and stress that, as industrial design is driven by business objective, the business-economic context of a product plays an essential role in determining in what manner design principles are applied in support of a particular design approach. The way in which design approaches for extending a product's lifetime become manifest in a tangible product can therefore differ markedly depending on the business-economic context of the product.

When product lifetime is defined solely in terms of functionality, the Inertia Principle (see section 2.3) in principle tends to favour those products that are close to, and high up on, the resisting obsolescence axis. However, with product lifetime now defined in terms of obsolescence (see section 2.4), the Inertia Principle can provide more nuanced guidance in how to best balance resource consumption with the preservation and restoration of economic value. As will be explained in more detail chapters 5 and 6, in many instances the way the business-economic and market context of a particular product changes over time can make a different overall design intention, e.g. a different combination of design directions, a more effective choice for minimizing the net environmental impact associated with product (including interventions for preserving and restoring of economic value) over its entire lifetime. In those instances, the position of the new product in the design space for extended product lifetime will then as a result not necessarily always move only upward (e.g. increase its potential for resisting obsolescence) but may also (or instead) need to move sideward and outward (i.e., increase its potential for postponing and reversing obsolescence). In chapter 6 we will go deeper into the question of whether some design directions can be expected to be more successful than others in a particular business-economic context.

Each point in the three-dimensional design space for preserving product integrity represents a unique combination of designing for resisting, designing for postponing and designing for reversing obsolescence. In theory, the possibilities for designing products with an extended product lifetime are endless. In practice, however, it is the fit of the actual product with its business-economic context that determines whether a particular combination for a particular product will be successful, i.e., whether a potential for preserving product integrity designed into a product can be realized in a particular business-economic context.

In that sense, designing for extended product lifetime is no different from any other form of industrial design: the extent to which a product designed for extended product lifetime is able to simultaneously help realize the desired results for customers and for businesses ultimately determines its commercial viability and success. However, the design principles for postponing and reversing obsolescence as currently presented in literature do not provide sufficient resolution to discriminate between design approaches. The design approaches differ not because they are supported by different design principles. They differ because of *how* these design principles are applied in support of a particular design approach. Just like product lifetime itself (see sub-section 2.4), the design approaches for designing a potential for postponing or reversing obsolescence into a product can no longer be considered a mere collection of engineering qualities to be objectively designed into a product.

As the business-economic context of a product plays an essential role in how design principles are used and how design approaches pan out in an actual product (see examples discussed above) we therefore propose to turn the design *approaches* for extended product lifetime discussed in the previous (sub-)sections into design *strategies* for extended product lifetime by making the aim of achieving this fit with the business-economic context an integral part of their definitions. We furthermore propose to incorporate the observation that industrial design can only design a potential for preserving product integrity into the definitions to highlight the need for cooperation with professionals from other business functions. Lastly, this thesis proposes to incorporate the concept of product integrity into the definitions to reflect that the design strategies are aimed at designing products that facilitate, though at the same time require as little as possible, deliberate intervention for postponing or reversing obsolescence, thereby safeguarding conformity to the Inertia Principle at the product level. The resulting typology for design strategies for preserving product integrity is presented in table 3.8.1.

3.9 DISCUSSION AND CONCLUSIONS

Chapter 3 set out to identify design interventions that would support the design approaches for preserving product integrity from the typology that was presented at the end of chapter 2 and develop the design approaches into a set of actionable design strategies for preserving product integrity. We found that virtually all of the eight design approaches for preserving product integrity are supported by the same set of design principles and that as a result, the use of a particular design principle in support of one design approach also tends to effect other approaches. This led to the introduction of the concept of a three-dimensional design space for preserving product integrity. Because of this interdependency, we considered the underlying design principles by themselves insufficient basis for discrimination between design strategies for preserving product integrity and argued that it rather is the intention with which these design principles are applied as part of the various design approaches for preserving product integrity that separates one design strategy from another: A design that facilitates, for instance, maintenance or repair for one actor can turn out to be impossible to maintain or repair for the other. Product designers aiming to design for maintenance and/or repair need to ask the question: Who will perform the maintenance or repair and where? Is it a layman user at home, a professional in the workshop, or perhaps a robot at the manufacturer? Although the typology for design strategies for preserving product integrity proposed in this chapter does not provide answers to such questions, it does acknowledge that the answers to these questions ultimately determine how underlying design principles will be applied. They may, for instance, determine to what extent a manufacturer chooses to limit or allow access to the workings and innards of its products. It follows that design for preserving product integrity needs to be applied in conjunction with business models that allow the (repeated) capture of economic value over time. For example, in order to make a product that was designed for remanufacturing really work, obsolete products need to be consistently returned to the original equipment manufacturer to be re-manufactured. This requires arrangements for reverse logistics and a transactional model that allows the (re)manufacturers to retain economic control of their product over time. Building on the above and on the finding from chapter 2 that the duration of product use cycles and product lifetime are not solely determined by the physical properties of the isolated product (Cooper, 2010), but rather by the perceived value within its wider context, we concluded chapter 3 with a new typology for design strategies for preserving product integrity, comprised of eight design strategies that take into account the particular business context of the tangible product to be designed, such as the business model it is embedded in.

Design Strategies for Preserving Product Integrity

Design direction **Resisting obsolescence**	*Design direction* **Postponing obsolescence**	*Design direction* **Reversing obsolescence**
Design strategy **Design for Emotional Durability**	*Design strategy* **Design for Maintenance**	*Design strategy* **Design for Recontextualizing**
Designing into a product a potential for remaining wanted over a long period of time, in a way that best matches the business-economic context of that product, and best supports the preservation of product integrity over the entire lifetime of the product.	Designing into a product a potential to undergo and facilitate the performance of inspection and/or servicing tasks at regular intervals, to retain a product's functional capabilities and/or cosmetic condition, in a way that best matches the business-economic context of that product, and best supports the preservation of product integrity over the entire lifetime of the product.	Designing into a product a potential to facilitate the use of an obsolete product (or its constituent components), without any remedial action, in a different context than it was used in as it became obsolete, in a way that best matches the business-economic context of that product, and best supports the preservation of product integrity over the entire lifetime of the product.
Design strategy **Design for Physical Durability**	*Design strategy* **Design for Repair**	*Design strategy* **Design for Refurbishing**
Designing into a product a potential for withstanding wear, stress, and environmental degradation and remaining able to fulfil all physical functions for which it was designed over a long period of time, in a way that best matches the business-economic context of that product, and best supports the preservation of product integrity over the entire lifetime of the product.	Designing into a product a potential for X, in a way that best matches the business-economic context of that product, and best supports the preservation of product integrity over the entire lifetime of the product.	Designing into a product a potential the process of returning an obsolete product to a satisfactory working and/or cosmetic condition, that may be inferior to the original specification, by repairing, replacing or refinishing all major components that are markedly damaged, have failed, or that are on the point of failure, even where the customer has not reported or noticed faults in those components. Generally, any warranty on a refurbished product applies to all major wearing parts but is less than that of a newly manufactured equivalent, in a way that best matches the business-economic context of that product and best supports the preservation of product integrity over the entire lifetime of the product.
	Design strategy **Design for Upgrading**	*Design strategy* **Design for Remanufacturing**
	Designing into a product a potential to undergo and facilitate interventions for enhancing, relative to the original design specifications, a product's functional capabilities and/or cosmetic condition, in a way that best matches the business-economic context of that product, and best supports the preservation of product integrity over the entire lifetime of the product.	Designing into a product a potential to undergo and facilitate a series of industrial processes in a factory environment, whereby an OEM (original equipment manufacturer), an OEM contracted third party, or a third party licensed to carry the OEM brand name, disassembles obsolete products into components, to a level as far down as needed to bring as many of those components as considered eligible after testing back to at least OEM original performance specifications and recombines those components—generally originating from different used products—with as few as possible new parts, to manufacture new products of a similar type and specification, that result in a new product with a warranty that is identical to that of an equivalent product manufactured out of all new parts. in a way that best matches the business-economic context of that product and best supports the preservation of product integrity over the entire lifetime of the product.

Table 3.8.1: Typology of design strategies for preserving product integrity: two strategies for resisting obscolescence, three strategies for postponing obscolescence and three strategies for reversing obscolescence.

REFERENCES CHAPTER 3: DESIGNING FOR PRESERVING PRODUCT INTEGRITY

Aguirre, D. (2010). *Design for Repurposing – A sustainable design strategy for product life and beyond* (Master thesis). Emily Carr University of Art + Design, Vancouver, BC, Canada.

Al-Jumeily, D., Hussain, A., & Macilwee, S. (2014). Investigation of green disposal of smartphones. *Advanced Materials Research, 1051*, 622-626.

Amezquita, T., & Bras, B. (1996, November). Lean remanufacture of an automobile clutch. In *Proceedings of First International Working Seminar on Reuse, Eindhoven, The Netherlands* (p. 6).

Apple (2016). *Liam - An Innovation Story*. Retrieved June 25th, 2016 from www.apple.com/environment/resources/. Also from www.youtube.com/watch?v=AYshVbcEmUc.

Apple (2017a). Apple inc. company website: www.apple.com

Apple (2017b). *Vintage and obsolete products*. Retrieved November 22nd, 2017 from https://support.apple.com/en-us/HT201624.

Apple (2017c). AppleCare. Retrieved November 22nd, 2017 from www.apple.com/support/products/.

Bakker, C., den Hollander, M., Van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. Leidschendam, the Netherlands: TU Delft Library/ Marcel den Hollander IDCR.

Bandai (2017). Company website: www.bandai.com. Tamagotchi product link: http://us.tamagotchifriends.com

Bartneck, C., Kulic , D., Croft, E., & Zoghbi, S. (2009). Measurement Instruments for the Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety of Robots. *International Journal of Social Robotics, 1*, 71-81.

Bijen, J. (2003). *Durability of engineering structures—Design, repair and maintenance*. Cambridge, UK: Woodhead.

Blom, J. O., & Monk, A. F. (2003). Theory of Personalization of Appearance: Why Users Personalize Their Pcs and Mobile Phones. *Human-Computer Interaction, 18*, 193-228.

BMA Ergonomics (2017). BMA Ergonomics company website: https://www.bma-ergonomics.com

Brennan, L., Gupta, S. M., & Taleb, K. N. (1994). Operations Planning Issues in an Assembly/ Disassembly Environment. *International Journal of Operations & Production Management, 14* (9), 57 – 67.

CRR (Centre for Remanufacturing and Reuse) (2009). *Thought Leadership – A description of the design for end-of-life process.* Retrieved October 4th, 2017 from http://www.remanufacturing.org.uk/pdf/story/1p295.pdf.

Chapman, J. (2005). Emotionally Durable Design. Objects, Experiences, and Empathy. London, UK: Earthscan.

Chapman, J. (2009). Design for (Emotional) Durability. Design Issues, 25(4), 29-35.

Chandler, J., & Schwarz, N. (2010). Use does not wear ragged the fabric of friendship: Thinking of objects as alive makes people less willing to replace them. *Journal of Consumer Psychology, 20*, 138–145.

Cooper, T. (2010). The Significance of Product Longevity. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (3-36). Farnham, Surrey, UK: Gower Publishing Limited.

Eastpak (2017). Eastpak company website: https://www.eastpak.com.

Egan, J. (2011). *Relationship Marketing – exploring relational strategies in marketing* (4th ed.). Harlow, Essex, UK: Pearson Education Limited.

Fairphone (2017). Fairphone company website: www.fairphone.com.

Fox, S. (2001). Managing product personalisation. *Engineering Management Journal*, *11*(4), 174-180.

Geyer, R., & Jackson, T. (2004). Supply loops and their constraints: the industrial ecology of recycling and reuse. *California Management Review*, *46*(2), 55-73.

Grosse-Hering, B., Mason, J., Aliakseyeu, D., Bakker, C., & Desmet, P. (2013, April). Slow design for meaningful interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (3431-3440). ACM.

Hagen-Zanker, J., & Mallett, R. (2013). *How to do a rigorous, evidence-focused literature review in international development, A Guidance Note*. London: Overseas Development Institute.

Hart, C. (2011). *Doing a literature review: Releasing the social science research imagination*. London, UK: SAGE.

Heider, F. & Simmel, M. (1944). An experimental study of apparent behavior. *The American Journal of Psychology, 57*(2), 43-259.

iFixit (2016a). Fairphone 2 teardown. Retrieved June 23rd, 2016 from www.ifixit.com/Teardown/Fairphone+2+Teardown/52523.

iFixit (2016b). iPhone 6 teardown. Retrieved June 23rd, 2016 from www.ifixit.com/Teardown/iPhone+6+Teardown/29213.

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

Kimura, F. (1997). Inverse manufacturing: from products to services. In *Computer Applications in Production and Engineering* (383-384). Springer US.

Kuo, T. C., Huang, S. H., & Zhang H. C. (2001). Design for manufacture and design for 'X': concepts, applications and perspectives. *Computers & Industrial Engineering, 41*, 241-260.

Lidwell, W., Holden, K., & Butler, J. (2010). *Universal principles of design, revised and updated: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Beverly, MA, USA: Rockport Publishers.

Loewe (2017). Loewe company website: www.loewe.com

Macnn (2010). *Apple MacBook sleep indicator set to human breathing rhythm*. Retrieved December 19th, 2015 from www.macnn.com/articles/10/08/27/dell.misses.mark.times.lsd.to.strenuous.activity/.

Merriam-Webster (2015b). Definition of "trust". *Merriam-Webster online dictionary*. Retrieved December 16th, 2015 from: www.merriam-webster.com/dictionary/trust.

Merriam-Webster (2016). Definition of "ergonomics". *Merriam-Webster online dictionary*. Retrieved June 19th, 2016 from: www.merriam-webster.com/dictionary/ergonomics.

Miele (2017a). Miele company website: www.miele.com/en/com/index.htm.

Mulder, W., Blok, J., Hoekstra, S. & Kokkeler, F. (2012). *Design for Maintenance – Guidelines to enhance maintainability, reliability and supportability of industrial products*. Twente, the Netherlands: University of Twente.

Mullaney, T., 2010. Design Case: Designing for Enduring Product Relationships. In Proceedings of 7th International Conference on Design and Emotion, 4-7 Oct 2010, Chicago, IL, USA.

Moss, M. A. (1985). *Designing for minimal maintenance expense: The practical application of reliability and maintainability*. Quality and Reliability series part 1. New York, NY, USA: Marcel Dekker.

Mugge, R. (2007). *Product Attachment* (Doctoral thesis). Delft University of Technology, Delft, the Netherlands.

Oakdene Hollins Ltd. (2007). *An Analysis of the Spectrum of Re-use*. Aylesbury, UK: Oakdene Hollins Limited. (Document reference: DEFR02 089 Reuse Review.doc).

Océ (2017a). Océ company website: https://www.oce.com.

Oxford Dictionaries (2015). "Animacy" definition. Retrieved December 16th, 2015 from www.oxforddictionaries.com/definition/english/animacy.

Oxford Dictionaries (2017). "Sacrificial" definition. Retrieved December 7th, 2017 from www.oxforddictionaries.com/definition/english/sacrificial.

Page, T. (2014). Product attachment and replacement: Implications for sustainable design. *International Journal of Sustainable Design, 2*(3), 265–282.

Piller, F., & Müller, M. (2004). A New Marketing Approach to Mass Customisation. *International Journal of Computer Integrated Manufacturing, 17*(7), 583-593.

Saddleback Leather Co. (2016). Saddleback Leather Co. company website: www.saddlebackleather.com.

Schifferstein, H. N. J., Mugge, R., & Hekkert, P. (2004). Designing Consumer-Product Attachment. In D. McDonagh, P. Hekkert, J. Van Erp & D. Gyi (Eds.), *Design and Emotion: The Experience of Everyday Things* (pp. 327-331). London, UK: Taylor & Francis.

Schifferstein, H. N. J., & Zwartkruis-Pelgrim, E. P. H. (2008). Consumer-Product Attachment: Measurement and Design Implications. *International Journal of Design, 2*(3), 1-13.

Scholl, B. J. & P.D. Tremoulet (2000). *Perceptual Causality and Animacy. Trends in Cognitive Sciences*, 4(8), 300-308.

Schridde, S. (2014). *Murks? Nein danke!* **München, Germany: Oekom Verlag.**

Stahel, W. R. (2010). *The Performance Economy* (2nd ed.), Hampshire, UK: Palgrave Macmillan Hampshire.

Sundin, E. (2004). *Product and process design for successful remanufacturing* (Doctoral dissertation). Linköping studies in Science and Technology, Linköping Institute of Technology, Linköping, Sweden.

Sung, J., Guo, L., Grinter, R. E., Christensen, H. I. (2007). My Roomba is Ramboo: Intimate Home Appliances. In J. Krumm, G. D. Abowd, A. Seneviratne, T. Stranget (Eds.), *Proceedings of UbiComp 2007* (145-162), Ubiquitous Computing, 9th International Conference, Innsbruck, Austria, September 16-19, 2007. Berlin Heidelberg, Germany: Springer Science & Business Media.

Knorr-Bremse (2017). Knorr-Bremse company website: www.knorr-bremsecvs.com

Tokaya, G. E. (2013). *Exploring emotionally durable design strategies in the field of LED lighting* (Master's thesis). Delft University of Technology, Delft, the Netherlands.

VandenBos, G. R. (Ed.) (2007). *APA dictionary of psychology*, Washington, DC, USA: American Psychological Association.

Van Hinte, E. (1997). *Eternally Yours: Visions on Product Endurance*. Rotterdam, The Netherlands: 010 Publishers.

Van Nes, N. (2003). Replacement of Durables: Influencing product life time through product design (Doctoral thesis, Erasmus University Rotterdam, Rotterdam, the Netherlands).

Vezzoli, C. & Manzini, E. (2008). ***Design for Environmental Sustainability*. London, UK: Springer-Verlag London Limited.**

Vitsoe (2016). *606 Universal Shelving System*. Retrieved November 20th, 2017 from https://www.vitsoe.com/eu/606

Young, L. (2006). Trust: looking forward and back. *Journal of Business & industrial Marketing, 21*(7), 439-445.

3

4

CREATING AND CAPTURING VALUE FROM PRESERVING PRODUCT INTEGRITY

What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?

Chapter 4: Creating and Capturing Value from Preserving Product Integrity is partly based on Den Hollander, M., & Bakker, C. (2016). Mind the Gap Exploiter: Circular Business Models for Product Lifetime Extension. *Proceedings of the Electronics Goes Green, Berlin, Germany*, 6-9.

4.1 INTRODUCTION

Chapter 4 aims to provide an answer to sub-research question C: "What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?" The objective of this chapter is to create a typology for circular business models for preserving product integrity in a circular economy.

Knowing, and understanding the implications of, the business context envisioned for a new product is essential for industrial designers as it affects the both the selection of design strategies for preserving product integrity and provides industrial designers with information as to how the design principles that support these strategies can best be applied (see section 3.6). To determine which business contexts industrial designers can encounter when designing for preserving product integrity in a circular economy, chapter 4 sets out to explore and identify the options for businesses to create and capture economic value from preserving product integrity in a circular economy.
After a brief introduction of the concepts of business model and business model types (a more extensive discussion can be found in Appendix B: The Business Model and Related Concepts), chapter 4 reviews of the literature from the fields of (sustainable) design and the business sciences, proposes a new definition of the concept of a circular business model, and subsequently develops and presents a new typology for circular business models for preserving product integrity.

4

The Current Prevalence of Sell More, Sell Faster
The vast majority of business built around tangible products use a business model type that is based on the transfer of ownership rights to the tangible product (Malone et al., 2006). In essence, this is the same type of business model that has been used for trading industrially manufactured products since the early days of the first Industrial Revolution, starting with Josiah Wedgwood's earthenware business in the U.K., over 200 years ago (Forty, 1989). The defining characteristic of this business model type, which from here on we will refer to as "Sell More, Sell Faster" (Bakker, Den Hollander et al., 2014, p.10), is that its main source of revenue consists of repeated one-time product sales. Businesses operating according to this business model archetype aim to 1) minimize production cost per unit of product, 2) maximize the amount of profit per transaction, 3) maximize the number of transfer of ownership rights transactions per unit of time and 4) repeat the process for as long as profitable and possible.

If this Sell More, Sell Faster business model type is applied in an unsaturated market (as was the case with Josiah Wedgwood in 1789 (Forty, 1989)), long product lifetime can be considered a business asset rather than a liability, as it may help strengthen a brand's reputation. However, when applied in a saturated marked (as most markets for durable consumer goods in our current Western economies are (Bayus, 1991)), long product lifetime quickly turns into a potential cause of problems. With the vast majority of purchases in a saturated market being replacement purchases (Bayus, 1991), a product's potential for a long lifetime is commonly perceived as a liability in most companies that use a Sell More, Sell Faster 'business model type because long product lifetimes could lead to a reduction in sales volume if users would decide to hold on to their current products longer. In Sell More, Sell Faster based companies, long product lifetimes are often furthermore considered evidence that products are too well made and seen as a signal that there is room for reducing production costs and thus increasing profit margin per unit.

The Need for Circular Business Models for Preserving Product Integrity

In the conventional sales transaction (e.g. the transfer of ownership rights to an asset (Malone et al., 2006)) that lies at the heart of the Sell More, Sell Faster 'business model type, the total exchange value (Bowman & Ambrosini, 2000), e.g. the financial return on perceived use value (Bowman & Ambrosini, 2000) created, in theory is captured in the instant of transaction (Bowman & Ambrosini, 2000; Herman, 1981). What happens with the item after the moment of sale or how long it will last its new owner therefore is – with the exception of brand reputation considerations and legal requirements (e.g., product liability, warranty and environmental regulations) – of little to no commercial interest to the seller and largely outside their span of control (Erler & Rieger, 2016; Malone et al., 2006).

In a circular economy, however, products are not allowed to disappear from the economic system as waste but must remain part of the resource loop, either in use or obsolete as presources awaiting renewal. In a circular economy, the economic and environmental value of materials is preserved by keeping them in the economic system for as long as possible, preferably by lengthening the useful lifetimes of products formed from them and, when lifetime extension at product level is no longer possible for environmental or economic reasons, by looping products back into the manufacturing process so their constituent materials can be reused. However, long-lifetime products and designing a potential for a long product lifetime into products will only become of commercial interest to a business, and thus only become an integral part of business goals and strategies, if these products can be embedded in business model types that are built in such a way that long-life products 1) directly or indirectly lead to structural cost or risk reduction and/or 2) directly or indirectly lead to structural revenue increase.

With the recent rise in attention for the circular economy concept (Korhonen et al., 2018; Bressanelli et al., 2017; Linder & Williander, 2017; Prendeville & Bocken, 2017; Geissdoerfer et al., 2016; Lewandowski, 2016; Rizos et al., 2016), the need for definition and classification of circular business model types for preserving product integrity, i.e., business model types that can profit from long and extended product lifetimes, intended for use by industrial designers (and business professionals) has been recognized and articulated in the literature (Bocken et al., 2016; Bocken et al., 2014; Boons & Lüdeke-Freund, 2013).

Chapter 4 sets out to meet this need and develop a typology for circular business models for preserving product integrity.

4.2 METHODOLOGY

Gathering Data – Review of the Literature

A review of the literature on business models and business model classifications is done to find out how the current literature defines the concept of a circular business model and to what extent the current literature contains business model types that are able to create and capture value from preserving product integrity in a circular economy. Jacob (2004) defined the concept of classification as the *"systematic arrangement of classes of entities based on analysis of the set of individually necessary and jointly sufficient characteristics that defines each class"* (p. 528) According to Marradi (1990), classifications *"are tools for conferring organization and stability on our thought about reality"* (p. 19). As they do not make assertions, they are neither right nor wrong (Marradi, 1990) but, *"like tools, they may be judged or found more or less useful for a particular purpose"* (Marradi, 1990, p. 19).

The review of the literature is based on the procedures described by Hagen-Zanker and Mallet (2013) as discussed in section 1.5 Research Design and draws predominantly from scientific publications but also grey literature in the fields of the business sciences and (sustainable) product design. The initial body of literature, limited to documentary sources in the English, Dutch or German language but without limits to publication date, is compiled from the search results returned by Google Scholar, for (combinations of) search terms related to (circular) business models and business model classifications: business model*, business model classification*, business model type*, business model typology, circular, classification*, circular business model*, strategy, taxonomy, value, value proposition, Using snowballing, new keywords that emerge, such as product service system, are added to the initial set. The results of the searches were scan-read to determine, based on the over 20 years of hands-on experience of the author in the fields of commercial industrial design and sustainable design and erring on the side of caution, whether they pertained to product design, product design for extended lifetimes, circular economy, sustainability and business in a manner that was potentially relevant to the topic of the research. Clearly irrelevant results, for example highly technical econometric or computing related papers, were discarded before storing the results in a software-based retrieval system and assigning (additional) keywords to them for later reference.

In total, over 125 articles are studied in detail in order to gain a deeper understanding of the topic, identify the *seed literature* (works of research on the topic considered as fundamental in the specific field) and to detect similarities, discrepancies, inconsistencies, and/or contradictions (Hart 2011).

Processing Data – Developing a Typology for Circular Business Models for Preserving Product Integrity

We begin by reviewing the literature to find out how it defines circular business models. Based on the findings of this review, we propose a new definition of the circular business model concept. Next, the literature review is continued to find out to what extent existing business model classifications classify business models according to their circularity and/or ability to create and capture value from preserving product integrity Based on the findings from this review, we develop a new typology for circular business models for preserving product integrity by synthesizing the types of the existing classifications and making our new definition of circular business model an integral part of the definitions for the new types of circular business models for preserving product integrity.

Two Approaches to Creating Business Model Types

In the literature, two major approaches can be found for making business model classifications: The *taxonomical* and the *typological* approach (Baden-Fuller & Haefliger, 2013). The taxonomical approach is empirical (Bailey, 1994) and concerned with identifying patterns and groups in existing uses of the business model concept. It looks back at empirical work and aims to create structure from that (Baden-Fuller & Haefliger, 2013). The typological approach, by contrast, is theoretical (Smith, 2002; Bailey, 1994), looks forward and *"emphasises the* *dimensions of the* [business] *model rather than its consequences"* (Baden-Fuller & Haefliger, 2013, p. 420). It is the latter approach that is used in the thesis. The result of a typological approach to classifying business models is a business model typology, in our case a typology for circular business models for preserving product integrity. A typology is a collection of conceptual business model types that is structured by considering the (dis)similarities between them across multiple dimensions (Bailey, 1994) – or bases for division (lat. *"fundamenta divisionis"* (Marradi, 1990, p. 3) – at the same time (Marradi, 1990).

Conceptual Typologies in Research: Advantages and Drawbacks
The use of conceptual typologies in research in general can have many advantages. They can, for example, help reduce complexity, provide a basis for comparison and, as mentioned above, can be used for heuristic purposes (Bailey, 1994). They can, however, also have some drawbacks (Bailey, 1994). Three potential pitfalls are worth mentioning explicitly with regard to business model types as they can be avoided, or their effects be mitigated, once they are recognized (Bailey, 1994).

The first is that a typology is only as good as the selection of the set of variables or bases for division (Marradi, 1990) used in creating them (Bailey, 1994). The second is the risk of reification, *e.g. "the possibility that theoretical constructs that do not exist empirically will be "reified" and treated as "real" empirical entities"* (Bailey, 1994, p.15). The third is their inherent dependency on what Bailey (1994) calls *"the logic of classes"* (p. 16). Types are discrete, and entities are therefore classified as either this or that, either black or white, whereas in some instances reality is more continuous and often contains various shades of grey. A typology cannot always adequately reflect these 'shades of grey. In the words of Bailey (1994), however, and notwithstanding its potential pitfalls: *"a well-constructed typology can be very effective in bringing order out of chaos. It can transform the complexity of apparent eclectic congeries of diverse cases into well-ordered sets of a few homogenous types, clearly situated in a property space of a few important dimensions. A sound typology forms a solid foundation for both theorising and empirical research. Perhaps no other tool has such power to simplify life for the ... scientist"* (p. 33)

There is general agreement in the literature over when a (business model) typology can be considered sound. The primary criterion is that its classes and types need to be both mutually exclusive and collectively exhaustive (Mäkinen & Seppänen, 2007; Malone et al., 2006; Bailey, 1994; Marradi, 1990). In addition, a typology should exhibit parsimony or scientific elegance, e.g. it should be constructed, and it concepts should be formulated, in the most simple and economical manner (Mäkinen & Seppänen, 2007; Malone et al., 2006; Marradi, 1990). It is furthermore preferable when the classification is *"intuitively sensible"* (Malone et al., 2006, p. 5) and uses *"representative naming"* (Mäkinen & Seppänen, 2007, p. 743).

4.3 THE BUSINESS MODEL: CONCEPT AND CLASSIFICATION

This section provides a short introduction to the business model concept and how it will be considered and classified in this thesis. A more extensive discussion of the concepts discussed here can be found in Appendix B: The Business Model and Related Concepts.

The Business Model Concept
Analysis, classification and design of forms of doing business, all require a set of descriptive parameters with which the essential structure of any business, regardless of venture type, can be captured (Osterwalder, Pigneur & Tucci, 2005). This set of descriptive parameters can be found in the business model concept (Teece, 2010; Zott & Amit 2010; Richardson, 2008; Osterwalder et al., 2005). A business model defines the way in which a company creates perceived use value and customer surplus in the form of goods and services, and captures monetary exchange value (Bowman & Ambrosini, 2000) in return by trading these goods and services with their customers (Linder & Williander, 2015; Osterwalder & Pigneur, 2010; Teece, 2010; Richardson, 2008). Its position as the *"conceptual link between business strategy, business organisation and systems"* (Saxena, Deodhar & Ruohonen, 2017, p. 21), together with the fact that every business enterprise has one (Teese, 2010), makes the business model construct well suited for the systematic exploration and classification of different business structures that are conducive to preserving product integrity.

First coined by Bellman, Clark, Malcolm, Craft and Ricciardi (1957), the business model concept at present is widely used, both in management practice and scientific research (Wirtz, Göttel & Daiser, 2016; Klang, Wallnöfer & Hacklin, 2014), when referring to a description of the underlying structure of a business (Saxena et al., 2017; Wirtz, Pistoia, Ullrich & Göttel, 2016). Despite its widespread use and present popularity, however, it has so far been difficult to arrive at a single and universally accepted definition of the term (Saxena et al., 2017; Wirtz, Göttel & Daiser, 2016; Zott Amit & Massa, 2011; Al-Debei & Avison, 2010; Shafer, Smith & Linder, 2005; Osterwalder, 2004). As for the thesis, we want to arrive at a working definition and conceptualization of the business model construct at a level of complexity that is sufficient for use by industrial designers, we will focus on the commonalities between the different business model definitions from the current literature and adopt the business model definition as proposed by Osterwalder and Pigneur (2010):

"A business model describes the rationale of how an organization creates, delivers and captures value." (p. 14).

Classifying Business Models
Business models can be analysed and discussed on three levels: The conceptual level that addresses the question of what a business model is, the type level that addresses the question of which types of business models resemble each other and the instance level that addresses the question of what the business model of a specific company is (Osterwalder et al., 2005). Classification of different business models can (by definition) not take place on the first, conceptual, level. The second, business model type, level of business model analysis, however, does allow for –or rather arises as a result of – the process of making systematic conceptual distinctions between different business models (Osterwalder et al., 2005). The business model type level is where different groups, or types, of business structures are identified and named according to the extent they *"share common characteristics"* (Osterwalder et al., 2005, p. 9). We consider these descriptions the business model type level sufficiently abstract to serve industrial designers in their relatively fast and fluid, iterative, processes of creative idea generation and initial, tentative assessments of feasibility. At the same time, we deem them sufficiently detailed to allow for the conversion of an idea to the third, business model instance level of analysis at a later stage, for example when more quantitative and

4

detailed evaluation of feasibility to guide subsequent iterations, both with regard to business model and product design alternatives, are needed. For the remainder of the thesis the business model concept will therefore be discussed and explored at the business model type level.

The typological approach to classifying business models that we employ in the thesis (see section 4.2) recognizes *"value creation"* (Baden-Fuller & Haefliger, 2013, p. 420). e.g. how a company creates, preserves and delivers value and *"value capture"* (Baden-Fuller & Haefliger, 2013, p. 420). e.g. how a company identifies and (re)connects with its customers, as the two most important dimensions of the business model. Forming the theoretical basis for the development of typological categorisations that can help to identify business model types (Baden-Fuller & Haefliger, 2013), this classic binary division is generally accepted in the business model literature (Saxena et al., 2017; Linder & Williander, 2015; Baden-Fuller & Haefliger, 2013; Teece, 2010; Osterwalder & Pigneur, 2010; Richardson, 2008) and is therefore adopted for the development of a typology for circular business models for preserving product integrity in this thesis.

4.4 CIRCULAR BUSINESS MODELS: A REVIEW OF THE LITERATURE

In this section, we review the literature to find how it defines the concept of a circular business model. Based on our findings, we propose a new definition for the concept of a circular business model and the measure for business model circularity.

Circular Business Models

The circular economy concept, in its most recent incarnation, is of much more recent date than the business model concept. The same can be said for the definitions for the circular business model concept in the current literature (e.g. Bocken et al., 2016; Lewandowski, 2016; Linder & Williander, 2015; Scott, 2015; Mentink, 2014).There is general agreement in the literature that circular business models are business models that are in line with the five main principles of the circular economy, listed by Lewandowski (2016) as *"(1) Design out waste/Design for reuse, (2) Build resilience through diversity, (3) Rely on energy from renewable sources, (4) Think in systems, (5) Waste is food/Think in cascades/Share values (symbiosis)"* (p. 5). How a circular business model is defined, however, is closely linked to how the circular economy concept is interpreted and defined. Scott (2015) defined the circular economy as *"a concept used to describe a zero-waste industrial economy that profits from two types of material inputs: (1) biological materials are those that can be reintroduced back into the biosphere in a restorative manner without harm or waste (i.e,. they breakdown naturally); and, (2) technical materials, which can be continuously re-used without harm or waste"* (p. 6). Where Scott (2015) aimed to connect the circular economy concept with that of sustainability by subsequently defining the latter as *"the capacity to continue in the long term and, at the same time, a mechanism that enables the circular economy to work"* (Lewandowski, 2016, p. 5), Mentink (2014) put more distance between the two. Mentink (2014) argued that, although circular business models *"can serve sustainability goals"* (p. 33), *"the circular economy does not fundamentally aim for sustainable development"* (p. 22). In Mentink's (2014) view, the aim of a circular business model, in contrast to that of a sustainable business model (Boons & Lüdeke-Freund, 2013), is not necessarily to balance economic, social and environmental needs (Mentink, 2014). Mentink (2014) instead focused on the economic and environmental aspects and proposed to define a CBM as *"the rationale of how an organisation creates, delivers and captures value with and within closed material loops"* (p. 35), whereby Mentink (2014) noted that a circular business model does not need to close material loops all by itself in order to qualify as circular. A business model can also be considered circular if it is a part of *a coordinated closed loop of multiple CBMs*, in which each individual circular business model is responsible for its own specific part of the total closed loop. These coordinated closed loops made up of multiple businesses are in line with the findings of Linder & Williander (2015), i.e., *"a circular business model implies a return flow to the producer from users, though there can be intermediaries between the two parties"* (p. 2), the *"modular approach"* (p. 246) for *"business models for industrial ecosystems"* (p. 246) as proposed by Tsvetkova & Gustafsson (2012), and the *"collaboration mechanisms"* (p. 226) as described by Hellström, Tsvetkova, Gustafsson and Wikström (2015). Based on their observation mentioned above, Linder & Williander (2015) furthermore proposed that *"business model circularity is determined by the fraction of new products that come from used products"* (p. 3). The definition of a circular business model by Bocken et al. (2016) is in line with that by Mentink (2014) as Bocken et al. (2016) left out the social component of sustainable business models from their definition of a circular business model as well. Bocken et al. (2016), referencing Ayres (1994), also emphasized the closing of material loops, approaching the circular economy concept from the direction of Industrial Ecology: *"The ambition level of an industrial ecology is to achieve an ideal state, one which resembles nature most. Such a system would be characterized by "complete or nearly- complete internal cycling of materials"* (p. 308). According to Bocken et al. (2016), circular business models are business models that *"enable economically viable ways to continually reuse products and materials, using renewable resources where possible"* (p. 308). Linder & Williander (2015) proposed to define a circular business model as *"a business model in which the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings"* (p. 2). Although the latter definition brings together both the more business model oriented definition by Mentink (2014) and the more reuse of products and renewable resources oriented description of Bocken et al. (2016), it only contains the business logic of value creation but not that of value capture that is part of Mentink's (2014) definition and not that of value delivery that is generally also considered an integral part of the business model concept (Saxena et al., 2017; Linder & Williander, 2015; Teece,2010; Osterwalder & Pigneur, 2010; Richardson, 2008).

The most important insight emerging from the literature review of the existing definitions for circular business models above, is that none of the current definitions explicitly acknowledge the absolute end-goal of a circular economy to mimic a cyclic Type III ecology (Graedel & Allenby, 2003; Lifset & Graedel, 2002) (see section 1.2) as closely as possible (WRAP, 2017; Bocken et al.2016; EMF, 2015; 2014; 2013; 2012), but rather continue to view circular business models from a relative perspective on sustainability. Although Bocken et al. (2016) are clear on the absolute ambition level of a circular economy, i.e., *"a complete or nearly-complete internal cycling of materials"* (p. 308), their definition of a circular business model does not explicitly reflect this. Although the phrase *"continually reuse products and materials"* (Bocken et al., 2016, p. 308) does refer to closed material loops, it is used without the addition of an absolute quantifying term such as "all" or "to a maximum extent". A similar open-ended stance with regard to the amount of waste and lack of absolute quantifiers can be recognized in the definitions as proposed by Linder & Williander (2015) and Mentink (2014). Furthermore, none of the circular business model definitions or descriptions from the current literature cover all three elements of the business rationale, i.e., creation, delivery and capture of value, that are generally considered part of the business model concept (Saxena et al., 2017; Linder & Williander, 2015; Teece,2010; Osterwalder & Pigneur, 2010; Richardson, 2008).

We therefore propose a new definition of a circular business model, in which the absolute goal of a circular economy is an integral part of the definition and terms pertaining to material loops or resources used in the current definitions are substituted with some of the new definitions and descriptions pertaining to material loops or resources that were presented in chapter 2, e.g., presources and leakage:

A *circular business model* describes how an organisation creates, delivers and captures value in a circular economic system, whereby the business rationale is designed in such a way that it preserves product integrity to a maximum extent, minimizes leakage and resorts to the use of resources in the process of creating, delivering and capturing value only when the options for using presources have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible.

The new definition builds on and integrates findings from the literature reviewed in the current and previous chapter(s), and at the same time expands on the existing definitions of circular business models (Bocken et al., 2016; Lewandowski, 2016; Linder & Williander, 2015; Mentink, 2014). Most importantly, it explicitly acknowledges the absolute environmental goal of the circular economy concept. This is reflected in the definition by the use of absolute quantifiers like to a maximum extent, minimizes and by stating the ideal end goal of the absolute approach that the circular economy concept in our view represents, i.e., resorts to the use of resources in the process of creating, delivering and capturing value only when the options for using presources have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible. At the same time, however, its formulation, i.e., minimizes leakage and most complete … possible, reflects that the newly proposed definition acknowledges and accepts the practical limitations to achieving this absolute goal as imposed by physics (e.g., a certain amount of leakage, for example by dissipation, is unavoidable (Ciacci et al., 2015) in many real-world situations) and resulting from the freedom of choice of individuals that is a fundamental value of our society (e.g., barring exceptional circumstances, such as war or natural disasters, it is undesirable (and unlawful) in our society to force people into an agreement to acquire or part from products at a certain time against their will). In line with the definitions of a circular business model by Bocken et al. (2016) and Mentink (2014), the newly proposed definition does not contain the social component of sustainable business models and approaches the circular economy concept from the direction of Industrial Ecology. Expanding on the existing definitions of circular business models the newly synthesized definition contains all three elements of the business rationale as mentioned above. By furthermore providing the context for the circular business model, i.e., in a circular economic system, the definition stresses that the circular business model operates in an economic system where waste is no longer allowed. By stating that the business rationale is designed in such a way that it preserves product integrity to a maximum extend, the definition introduces a term from the new terminology proposed

in chapter 2 and explicitly makes clear that a circular business model gives precedence to preserving product integrity over recycling. By incorporating the overall environmental goal, however, i.e., to achieve the most complete cycling of materials within the larger economic system possible (Ayres, 1994), the definition, however, also stresses the importance of recycling and acknowledges that preserving product integrity - or extending product lifetime - is not always the best approach from an environmental point of view (Bakker, Wang, et al., 2014; Van Nes & Cramer, 2005; Charter & Tischner, 2001; Tischner et al., 2000). In some instances of energy consuming products, for example, a timely replacement of a product by a newer, more energy efficient version can result in greater net reduction of the environmental load (e.g. Bakker, Wang, et al., 2014). In addition, the latter part of the statement of the overall goal, i.e., the larger economic system, makes room to accommodate circular business models that are part of *a coordinated closed loop* as described earlier (Hellström et al., 2015; Mentink, 2014; Tsvetkova & Gustafsson, 2012). It follows from the above that companies in such a coordinated closed loop, in addition to the ability to appropriate (their part of) the exchange value, i.e., have ownership and/or economic control over tangible products, business model types for creating and capturing value from preserving product integrity in a circular economy must also have the ability to retain and/or reacquire ownership and/or economic control over (their part of) these tangible products when they become obsolete, i.e., become presources.

Two inferences can be drawn from the newly proposed circular business model definition that can be used to distinguish business model types that could be circular if properly structured at instance level from those that because of their (lack of) specific properties can never be circular at instance level. The first is that in order to be able to preserve product integrity to a maximum extent, circular business models for preserving product integrity must - in addition to the ability to appropriate (their part of (Hellström et al., 2015; Mentink, 2014; Tsvetkova & Gustafsson, 2012)) the exchange value, i.e., have ownership and/or economic control over tangible products (see above) - have the ability to retain and/or reacquire ownership and/or economic control over (their part of (Hellström et al., 2015; Mentink, 2014; Tsvetkova & Gustafsson, 2012)) these tangible products when they become obsolete, i.e., become presources.

The second inference is based on Moeller & Rolf's (2001) description of the objective of product design as "*the development of parameters that define the product and the process of its production. The parts list specifies in detail the raw materials and preliminary products that are used in the manufacturing process. Process engineering derives production plans from the parts list. Production plans describe the predecessor-successor relationship in, each production step while considering the possibilities and limitations of the available manufacturing facility. The final step is to produce, deliver and service the product*" (p. 1). When the new circular business model definition is considered in light of the above description, it becomes evident that circular business model types that do not have control over the design of the tangible product can never qualify as circular as they will not have the power to specify how their products are produced. Malone et al. (2006) considered a business to be an original equipment manufacturer when it controls *"substantial (more than 50% of the value) design of the product"* (p. 7), regardless of whether *"it outsource*[s] *all the physical manufacturing of its product"* (p. 7) or not.

4

Business Model Circularity
The explicit acknowledgement of the absolute nature and goal of a circular economy that resulted in the new circular business model definition proposed above also has consequences for the measure for *"business model circularity"* (p. 3) as proposed by Linder and Williander (2015). The current measure for business model circularity, defined by Linder and Williander (2015) as *"the fraction of new products that come from used products"* (p. 3), may prove useful to a limited extent in the transition from a linear (i.e., a linear type I ecology based (Graedel & Allenby, 2003; Lifset & Graedel, 2002)) economy towards a less linear (i.e., a quasi-cyclic type II ecology based (Graedel & Allenby, 2003; Lifset & Graedel, 2002)) economy (see section 1.2). As the definition as proposed by Linder & Williander (2015) is still rooted in relative, linear economy thinking, however, we deem it insufficient for capturing the (differences in) circularity of business models in a circular economy and – after explaining why we think this to be so – will therefore propose an expanded measure of business model circularity in the remainder of this section.

Contrary to what the measure for business model circularity as proposed by Linder & Williander (2015) suggests, manufacturing new products from used products is not the only (nor always the most effective) option available to circular business models to support the absolute goals of a real-world circular economy, i.e., achieve the most complete cycling of materials within the larger economic system possible. As we explained in chapter 2, next to closing resource loops through recycling, minimizing the speed at which (p)resources flow through our economic system through the various interventions for preventing, postponing and reversing obsolescence can also help minimize leakage that is unavoidable in a real-world circular economy and that inevitably occurs for example as a result of dissipation (Ciacci et al., 2015) Chapter 2 therefore introduced the distinction between design for preserving product integrity and design for recycling. Although both approaches are important to achieving the goals of a circular economy, their contributions are not equal. The Inertia Principle, *"do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured"* (p. 195), indicates that there is a clear preference with regard to the order in which (the various interventions for) design for preserving product integrity and design for recycling are performed, especially in a circular economy. The reason that recycling is last in Stahel's (2010) above quote is that it destroys all product integrity and added economic value that interventions for preventing, postponing and reversing obsolescence at product level strive to preserve to a maximum extent.

It follows that, in addition to the *quantity* of materials from used products that end up in new products (i.e., the basis of Linder & Williander's (2015) measure of business model circularity), the state or *quality* of used products that end up in new products and the timing of when used products end up in new products are also of major importance in determining the circularity of business models in a type III ecology based circular economy, where all new products in principle must come from used products (WRAP, 2017; Bocken et al., 2016; EMF, 2015; 2014; 2013; 2012; Graedel & Allenby, 2003; Lifset & Graedel, 2002). The only two exceptions to the above general circular principle are the influx of virgin resources needed to compensate for losses resulting from leakage, or the influx of virgin resources needed to increase the total amount of resources in circulation in the circular economic system.

Both from an environmental and a business-economic perspective, there are significant differences between products that for example are used for one year and those that are used for ten years before they have to be turned into new products, and between new products that consist for 95% of components and/or subassemblies acquired from obsolete products and new products that consist for 95% of materials acquired from obsolete products. These differences directly affect the amount of added economic value that is preserved over the lifetime of a product and therefore are especially relevant to circular business models in a type III ecology based circular economy.

In light of the above, we therefore propose the fraction of economic value added to (p) resources that is preserved over time as the new measure for business model circularity. The newly proposed measure expands on the measure proposed by Linder & Williander (2015) as it, in addition to taking into account the amount of (p)resources that is processed in the (p) resource loops, takes into account how and when (i.e., how frequently) these (p)resources are processed as well.

It may be evident from the above that the environmental business goal of every circular business model for preserving product integrity is to maximize business model circularity.

4.5 BUSINESS MODEL TYPES FOR PRESERVING PRODUCT INTEGRITY IN A CIRCULAR ECONOMY: A REVIEW OF THE LITERATURE

In this section, we review the literature to find out to what extent it contains business model types and classifications that classify business models according to their circularity and/or ability to create and capture value from preserving product integrity.

Classifications of Business Model Types for Preserving Product Integrity in the Current Literature
Although the potential economic benefits of product lifetime extension are recognized by many authors in various sub domains of the business sciences literature, such as operational management (e.g. Bartels et al., 2012; Linton & Jayaraman, 2005) and closed-loop supply chains (e.g. (e.g., Govindan, Soleimani & Kannan, 2014; Guide Jr. & Van Wassenhove, 2009; Linton & Jayaraman, 2005; Guide Jr., Harrison & Van Wassenhove, 2003). the ability to profit from product lifetime extension, or preserving product integrity, is generally not perceived as a basis for division resulting in a specific class of business model types, but rather as something that can be done in support of other business model types.

In the sustainability oriented literature, existing classifications of sustainable and/or circular business models (e.g., Bocken et al., 2016; Lewandowski, 2016; Van Renswoude, Wolde & Joustra, 2015; Bocken et al., 2014; Mentink, 2014; OPAi & MVO Nederland, 2014; Accenture, 2014) mostly employ potential *"mechanisms for delivering sustainability"* (Bocken et al., 2014, p. 45) as a bases for categorisation of business model types rather than the business model principles of *"value creation"* (Baden-Fuller & Haefliger, 2013, p. 420) and *"value capture"* (Baden-Fuller & Haefliger, 2013, p. 420) that are more widely accepted in classifications in the business science literature (e.g., Saxena et al., 2017; Linder & Williander, 2015; Baden-Fuller & Haefliger, 2013; Teece, 2010; Osterwalder & Pigneur, 2010; Richardson, 2008). As a result, business models in these classifications are often grouped together under headings such as *"produce on demand"* (Van Renswoude et al., 2015, p. 11), *"circular supplies"* (Accenture, 2014, p. 12), *"resource recovery"* (Accenture, 2014, p. 12), *"encourage sufficiency"* (Bocken et al., 2014, p. 52) or *"extending product value"* (Bocken et al., 2016, p. 313). The overview of circular business model types presented by Lewandowski (2016) for example is an illustration of the

4

present lack of clarity surrounding circular business model types. In Lewandowski's (2015) overview, an eclectic mix of design strategies, business model types, production processes and approaches to sustainability can be found, all classified as business model types in six main categories that are based on the main circular economy principles (Lewandowski 2016), i.e., *"Regenerate"* (p. 8), *"Share"* (p. 8), *"Optimise"* (p. 9), *"Loop"* (p. 9), *"Virtualize"* (p. 9), and *"Exchange"* (p. 9).

Although the classifications mentioned above may prove useful for other purposes, they provide little information as to the different underlying business structures for creating and capturing value and their (potentially) specific implications with regard to design for extended product lifetimes or preserving product integrity. This can be illustrated for example by the sustainable business model archetype categorisation proposed by Bocken et al. (2014). As can be seen in figure 4.4.1 below, preserving product integrity, in one form or another (e.g., through emotional and/or physical durability, maintenance, upgrading, recontextualizing, repair, refurbishing or remanufacturing) could prove beneficial for and even essential to many of the business model archetypes presented. As the ability to preserve product integrity, however, is not a basis for classification, it is spread out over multiple archetypes: The 'Encourage sufficiency' archetype for example lists 'Product longevity', the 'Create value from waste' archetype lists 'Sharing assets' and 'Remanufacture', and the 'Deliver functionality rather than ownership' archetype lists 'Design, Build, Finance, Operate (DBFO)' and various PSSs (Product-Service Systems).
However, whether and why certain business model archetype would benefit from a focus on a particular intervention for preserving product integrity or on one of more design strategies for preserving product integrity (e.g. design for physical durability or design for remanufacturing) over another, is hard to tell from the business model archetypes as they are arranged and shown in figure 4.4.1.

The Need for a New Typology for Circular Business Models for Preserving Product Integrity
From the literature review of business model classifications, it follows that the ability of a business model type to create and capture value from preserving product integrity is considered secondary, if at all, in current business model classifications. This has led to classifications in which business model types are often mixed from a circular product design point of view, i.e., the categories have been defined in such a way that they can contain both business models that are more conducive to life extension at product level and thus Design for preserving product integrity as well as those that are better suited for life extension at material level and thus Design for Recycling. This manner of classifying diffuses the notion that there is a distinct difference between the two (see section 2.5) and could make it less clear to industrial designers how to design products that are specifically tailored to, and therefore make the most of the environmental and economic potential of, either kind of business model.

We argue therefore that it in order to facilitate the design of products that are tailored to match business model types for creating and capturing economic value from preserving product integrity in a circular economy it is necessary to reconsider and refine existing categorisations of sustainable business models and develop a new typology for circular business model types for preserving product integrity in a circular economy.

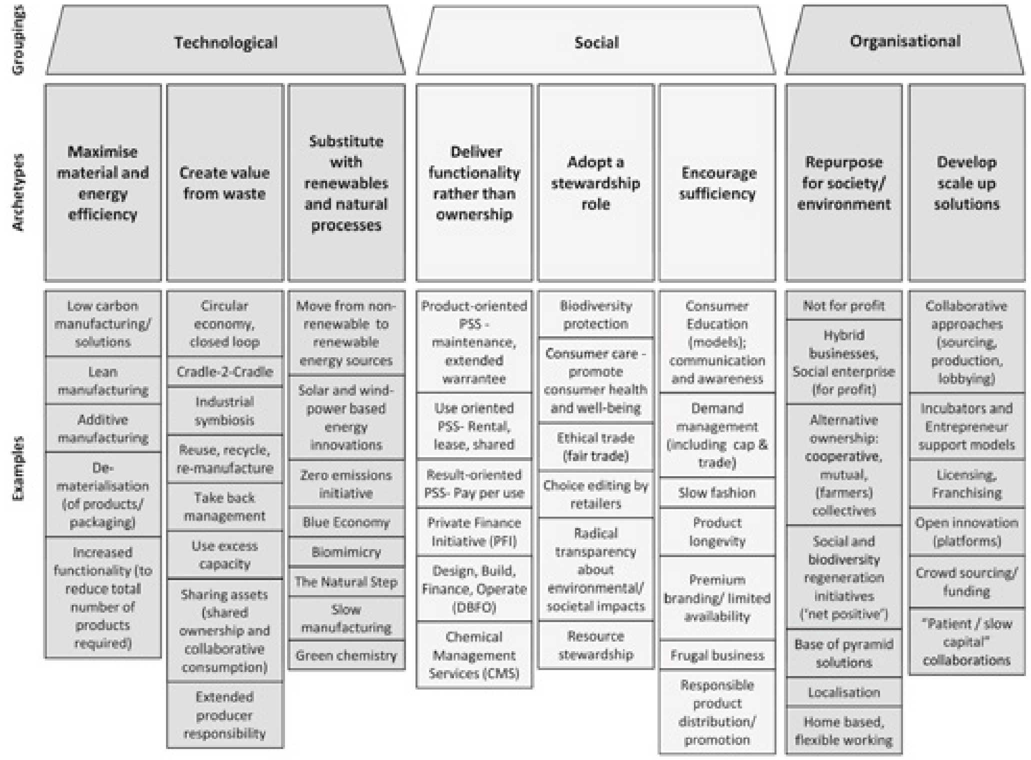


Figure 4.5.1: Sustainable business model archetypes as proposed by Bocken et al., 2014, p. 48.

Product-Service Systems
Although Product-Service Systems (PSSs) strictly speaking are not business model types (Tukker et al., 2006), we consider the literature on PSSs (e.g., Tukker, 2015, 2004; Gaiardelli, Resta, Martinez, Pinto & Albores, 2014; Reim et al., 2015; Boehm & Thomas, 2013; Park, Geum & Lee, 2012; Baines et al., 2007; Tukker & Van den Berg, 2006; Mont, 2004, 2002) to be a most useful starting point here. The PSS concept originated in the sustainability-oriented literature, for if devised and implemented well, a PSS can, next to economic benefits, offer substantial social and environmental benefits (e.g., Reim et al., 2015; Tukker, 2015; Gaiardelli et al., 2014; Beuren, Ferreira & Miquel, 2013; Boehm & Thomas, 2013; Kohtamäki, Partanen, Parida & Wincent, 2013; Mont et al., 2006; Sundin & Bras, 2005, Tukker 2004). In recent years, however, the PSS concept has also become part of other research fields such as Manufacturing, ICT, Business Management, Engineering and Design (Tukker, 2015; Boehm & Thomas, 2013). This is reflected in the many different definitions of the PSS concept in the literature (e.g., Reim et al., 2015; Tukker, 2015; Gaiardelli et al., 2014; Boehm & Thomas, 2013; Park et al., 2012; Baines et al., 2007; Tukker et al., 2006; Mont, 2004; Hockerts & Weaver, 2002; Manzini & Vezzoli, 2002; Mont, 2002; Brezet, Bijma, Ehrenfeld & Silvester, 2001; James, Slob & Nijhuis, 2001; Goedkoop, Van Halen, Te Riele & Rommens, 1999; Meijkamp, 1998; Manzini, 1996). Some of the earlier definitions, such as that by Mont (2004), Brezet et al. (2001), and James et al. (2001) explicitly include the aim of a PSS to reduce environmental load as an integral part of the definition. Most of the later definitions, however, like the following one by Boehm &

Thomas (2013) that is adopted for this thesis, do not: *"a Product-Service System (PSS) is an integrated bundle of products and services which aims at creating customer utility and generating value"* (p. 252.). Although the definition by Boehm & Thomas (2013) is one of the later PSS definitions that do not contain a direct reference to reducing environmental load, it is selected for the thesis nonetheless for two reasons. Firstly, as it is the result of a unique, cross-disciplinary (i.e., Information Systems, Business Management, Engineering and Design), research approach to defining the PSS concept (Tukker, 2015; Boehm & Thomas, 2013), it has been formulated with the express purpose to be acceptable to all disciplines involved (Tukker, 2015; Boehm & Thomas, 2013). Secondly, in line with the comprehensive typology for IPS (Integrated Product Services) as proposed by Park et al. (2012), the definition by Boehm & Thomas is one of the few definitions that, by using the term *integrated bundle*, reflects that in a PSS, products and services are developed in conjunction with the express intention be offered together and therefore cannot easily be separated. It is this characteristic that sets PSSs apart from other product-service based business model types listed by Park et al. (2012), such as *"Integrated Solution"* (p. 534), *"Functional Sales"* (p. 535), *"Functional Product"* (p. 535), and *"IPSO"* p. 535).

Product-Service Systems and Long Product Lifetimes

According to the PSS literature, the relative importance of an intangible service component to the value proposition can be considered an indicator of the ability of a business model type to profit from extended product lifetimes (e.g., Tukker, 2015). Tukker (2015) offered the following explanation as to why adding services to a tangible product can serve to promote product longevity:

> In product-oriented business models firms have the incentive to maximize the number of products sold. This is their principal method of boosting turnover, increasing market share, and generating profits. However, in service-oriented business models, in theory the incentive differs. Firms then make money by being paid for the service offered, and the material products and consumables that play a role in providing the service become cost factors. Hence, firms will have an incentive to prolong the service life of products, to ensure they are used as intensively as possible, to make them as cost – and material – efficiently as possible, and to re-use parts as far as possible after the end of the product's life. All of these elements could lead to a minimization of material flows in the economy while maximizing service output or user satisfaction (p. 76).

The literature repeatedly highlights the connection between product-service bases value propositions like PSSs and long product lifetime. Reim et al. (2015) for example, presented a systematic literature review of *"PSS tactics"* (Reim et al., 2015, p. 66) that could assist in making the transition from product-oriented business model types to service-oriented business model types. With regard to tactics pertaining to product design, their researched referred to several of the design strategies for preserving product integrity as presented earlier in chapter 3, stressing the importance of extended product lifetime to the success of service-oriented business model types. Beuren et al., (2013) presented product reuse, repair, upgrading as characteristic elements of PSSs. Oliva & Kallenberg (2003), expounding on the economic advantages of intangible services over products stated that *"substantial revenue can be generated from an installed base of products with a long life cycle"* (p. 160). In literature from the domain of relationship marketing, defined by Grönroos (1991) as *"to establish, maintain and enhance relationships with customers and other parties at a profit so that the objectives of the parties involved are met... by a mutual exchange and fulfilment of promises"* (p. 8), Grönroos (1997) for example observed that the share of the intangible service component (i.e., the importance of the relationship component) relative to the tangible product component in a product-service based value proposition can be considered an indication of the potential to create *"perceived value for customers over time"* (p. 407). This notion, that the larger the service component, the more conducive a PSS is to long product lifetimes, is supported by Stahel's (2010) concept of a *"Performance Economy"* (p. v).

Product-Service Systems as Business Model Types

Although the PSS concept and the business model concept (business sciences literature) are rooted in different disciplines, the *"overlap between the concepts from the two streams is striking"* (Tukker et al., 2006, p. 30). Tukker et al. (2006) observed

> what the sustainability-oriented literature calls a 'product-service' is nothing more and nothing less than a specific type of 'offering' or 'value proposition'. What the sustainability-oriented literature calls the 'system' is nothing more and nothing less than the combination of the value network, technological architecture and revenue model (p. 31).

Much like business model types, PSSs can therefore be considered to provide a type level description as to how perceived use value is created and delivered, and how exchange value is captured (Tukker et al., 2006). The parallels with between PSS types and business model types are particularly evident when the PSS designations and definition proposed by Hockerts and Weaver (2002) are put next to the "type of asset right traded" dimension from the business model typology (that classified business models according to the "type of asset" and "type of asset right traded" dimensions) as proposed by Malone et al. (2006). According to Hockerts and Weaver (2002)

> a pure product system is one in which all property rights are transferred from the product provider to the client on the point of sale ... A pure service system is one in which all property rights remain with the service provider, and the clients obtain no other right besides consuming the service. A product-service system is a mixture ... of the above. It requires that property rights remain distributed between client and provider, requiring more or less interaction over the lifetime of the PSS (Hockerts & Weaver as quoted in Tukker et al., 2006, p. 25).

When this idea is extended, and a PSS is conceptualized in business model terms, the PSS classification that is most commonly used in the PSS literature (Tukker, 2015; Van Ostaeyen, Van Horenbeek, Pintelon & Duflou, 2013) can also be used to classify business model types as shown in figure 4.5.2.

The above classification is founded on the notion that *"products and services are linked"* (Tukker et al., 2006, p. 23). There is general agreement in the literature on PSSs that the two never exist in isolation (Reim et al., 2015; Tukker et al., 2006) as *"in practice the provision of services involves a number of tangible and intangible elements, while the supply of products*

4

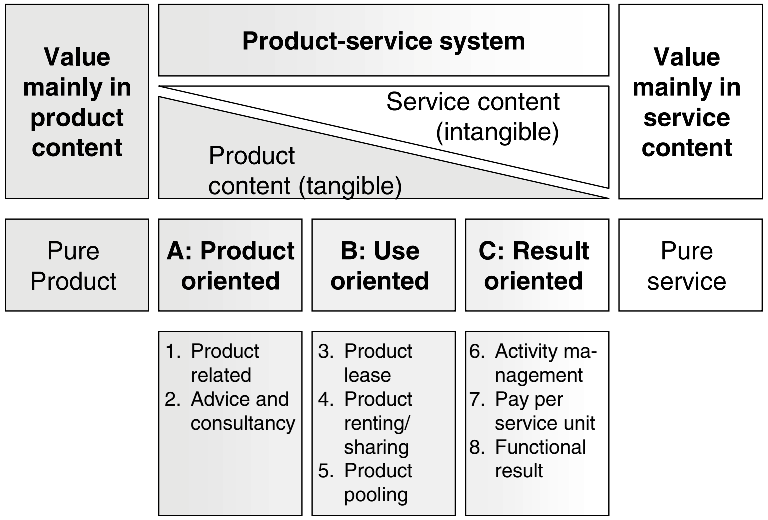


Figure 4.5.2: Using the most commonly used PSS classification to classify business model types: the product-oriented, use-oriented and result oriented business model types with the ratio of tangible product to intangible product (e.g. services) in their respective value propositions. Reproduced from Tukker et al., 2006, p. 23.

relies on the culmination of a long chain of services" (Tukker et al., 2006, p. 23). Instead of considering the (transfer of) ownership of a tangible product an end in itself, PSS-based business model typologies tend to view all tangible products as a means to an end, i.e., enabling the delivery of satisfaction to the customer (Manzini & Vezzoli, 2003). The above notions also find support in the literature on marketing from the domain of the business sciences, although the issue of how to conceptualize services (e.g., Lovelock & Gummeson, 2004; Vargo & Lusch, 2004; Zeithaml, Parasuraman & Berry, 1985) has not yet been resolved there (Kimbell, 2014). The two main options in the ongoing debate are that *"either (a) everything is a service"* (Kimbell, 2014, p. 49), following Vargo & Lusch's (2004) proposal *"that the conventional distinction between goods and services does not matter"* (Kimbell, 2014, p. 49), or *"(b) new ways need to be found to understand the specific qualities of organising for and consuming services, such as highlighting ownership and access to resources"* (Kimbell, 2014, p. 49), as proposed by Lovelock & Gummeson (2004).

The basis for division of the classification of value propositions shown in figure 4.5.2 is the ratio between the contribution of the tangible product and the intangible service component to the value proposition (Tukker et al., 2006). Each of the resulting categories of product-service based value propositions in turn has its own specific revenue model, describing how exchange value is captured from the perceived use value that is created. Combining the two (i.e., how value is created and how value is captured) results in the classification of PSS-based business model types shown in table 4.5.3, whereby the ability of a business model type to profit from long and extended product lifetimes increases from left (i.e., product-oriented based business model type) to right (i.e., result-oriented PSS-based business model type) (Stahel, 2010; Grönroos, 1997) as the role of the tangible product changes from being an object to be traded towards that of being a capital good, i.e., means of production.

Product-oriented PSS-based business model type	Use-oriented PSS-based business model type	Result-oriented PSS-based business model type
The provider trades the right of ownership to a product and offers services (such as advice in the most efficient use of the product) that are needed during the use phase of the product.	The provider trades the right of use to a product. The customer pays a regular fee for the, normally unlimited and individual, but sometimes sequentially shared, use of the product over a specified period of time. The provider keeps the ownership and often is responsible for maintenance, repair and control.	The provider agrees with the customer to deliver a result. The result is not connected to a particular technological system or tangible product.

Table 4.5.3: PSS-based business model archetypes, adapted from Tukker et al., 2006.

Although the PSS typology as presented in figure 4.5.3 has been criticized by Van Ostaeyen et al. (2013) for taking the *"allocation of property rights"* (p. 262) as a basis for classification and for being *"too strict"* (p. 262) and unable to accommodate finer, function-related, distinctions within the use-oriented and result-oriented categories, we have chosen to adopt it nonetheless for use in the thesis as we consider it *"more ... useful for* [our] *particular purpose"* (Marradi, 1990, p. 19) for two reasons. The first is that the allocation of property rights plays a central role in preserving product integrity as it is an indicator for the ability of a company to retain economic control over resources. The second reason is of a practical, methodological nature. The typology from table 4.5.3 is *"widely used in academic literature"* (Van Ostaeyen et al., 2013 p. 261) and many sustainability and design related research findings are linked to, and at the level of, its particular three-way PSS classification scheme (e.g. Gebauer, Joncourt & Saul, 2016; Armstrong, Niinimäki, Kujala, Karell & Lang, 2016; Cusumano, Kahl & Suarez, 2015; Reim et al., 2015; Tukker et al., 2006; Tukker, 2004, see chapter 6). As such, we deem the alternative PSS typology as proposed by Van Ostaeyen et al. (2013) to be of limited use and perhaps even counterproductive to our current research, in spite of the additional resolving power it offers.

An increase in the intangible product, or service, component of the value proposition of a business is not only beneficial from a resource point of view. For example Cusumano et al. (2015) and Oliva and Kallenberg (2003, p. 161) found that *"management literature is almost unanimous in suggesting to product manufacturers to integrate services into their core product offerings"* and provided a number of compelling business-economic reasons for companies to do so: 1) Combining services with products can *"give customers the confidence to make the purchase"* (Cusumano et al., 2015, p. 559), 2) Combined product-service offerings can be more competitive than stand-alone product offerings (Cusumano et al., 2015), 3) *"Services can help build deeper relationships with customers"* (Cusumano et al., 2015, p. 560), increasing the likelihood of future transactions with these customers (Cusumano et al., 2015), 4) *"Substantial revenue can be generated from an installed base of products with a long life cycle"* (Oliva & Kallenberg, 2003, p. 160), 2) *"services, in general, have higher margins than products"* (Oliva & Kallenberg, 2003, p. 160), 3) *"services provide a more stable source of revenue as they are resistant to the economic cycles that drive investment and equipment purchases"* (Oliva & Kallenberg, 2003, p. 160; Cusumano et al., 2015), 4) *"customers are* *demanding more services"* (Oliva & Kallenberg, 2003, p. 160) and lastly, 5) *"services, by being less visible and more labor dependent, are much more difficult to imitate, thus becoming a sustainable source of competitive advantage"* (Oliva & Kallenberg, 2003, p. 160).

Accepting the premise that products and services are inextricably linked (Reim et al., 2015; Tukker, 2015), i.e., that there is no such thing as a pure product or a pure service, the PSS-based business model types from table 4.5.1 meet two of the three requirements for circular business models for preserving product integrity that follow from the previous chapters and sections and are discussed below.

Built Around Tangible Products
The first requirement for business model types to qualify as a circular business model type for preserving product integrity, is that tangible products must be key to their ability to create perceived use value. The business model of a bicycle manufacturer for example would meet this requirement as tangible products, i.e., bicycles, are central to its ability to create perceived use value for its customers. The business model of a law firm, however, would not fulfil this first requirement. Although a law firm makes intensive of use desks, office chairs, computers, staplers and pens, it is the employees' applied expertise and not (their interactions with) these particular artefacts, that is the primary source of perceived use value for the clients.

Preserving Product Integrity is Essential to Continuity, Revenue and Profit
The second requirement for business model types to qualify as a circular business model type for preserving product integrity, is that they must be constructed in such a way that extended product lifetimes contribute positively and structurally to the continuity, revenue and profit (e.g. Stout, 2017; Heiskanen, 1996; Tukker et al., 2006) of the business venture, i.e., preserving product integrity must be recognized as a source of competitive advantage and therefore has strategic importance (e.g. Porter, 1998, 1996, 1980). To be able to systematically capitalize on the long lifetime potential of their products, i.e., make (a part) of the exchange value generated with the products flow into its coffers, a company must either own the products of which the lifetime is extended or be able to appropriate a part of the reimbursements paid for the use of those products (Bowman & Ambrosini, 2000). When a business manufactures and markets products that last a long time but has no structural solution in place to capitalize on this longer product lifetime, for example because its main source of revenue are replacement sales (Bayus, 1991) of tangible products (with sales used here as transactions that transfer ownership rights (Malone et al., 2006), it could see the long lifetime potential of their products threatening, instead of contributing to, its profits.

However, as can be deduced from the use of the phrase *"in service-oriented business models, in theory the incentive differs"* in the explanation by Tukker (2015, p. 76) as to why adding services to a tangible product can serve to promote product longevity presented earlier, as well as from the different definitions of the PSS concept in the literature, there is an acute awareness in the PSS literature that not every business model built around a combination of tangible products and intangible services will necessarily contribute to reducing the environmental load and/or be conducive to extended product lifetimes. Even those business models built around a combination of tangible product and intangible services that are developed with the express intention to – and that in principle can – reduce the environmental impact, if *"not developed carefully run the risk that the environmental potential will be offset by rebound effects and less careful behaviour"* (Beuren et al., 2013, p. 61).
To qualify as a circular business model type for preserving product integrity, business model types must therefore meet an additional, third, requirement.

Be Circular
The third requirement for business model types to qualify as a circular business model type for preserving product integrity is that they are circular. According to the newly proposed definition (see section 4.4), a business model is circular when the business rationale is designed in such a way that it preserves product integrity to a maximum extent, minimizes leakage and resorts to the use of resources in the process of creating, delivering and capturing value only when the options for using presources have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible.

As it is not self-evident from the current definitions of the PSS-based business models (e.g. Tukker, 2015; Beuren et al., 2013) that they meet this last requirement, we propose to develop the PSS-based business model types into circular business model types for preserving product integrity by making the newly proposed definition for a circular business model an integral part of the new business model type definitions. A new typology for circular business models for preserving product integrity resulting from this integration is presented in the next section.

4.6 A NEW TYPOLOGY FOR CIRCULAR BUSINESS MODELS FOR PRESERVING PRODUCT INTEGRITY

This section will present a new typology for circular business models for preserving product integrity by integrating the PSS-based business model types from section 4.5 with the newly proposed definition for the circular business model concept from section 4.4.

Combining the PSS based business model types with the new definition for the circular business model concept results in a new typology for circular business models for preserving product integrity that consists of three types. These will be discussed below.

4.6.1 The Classic Long Life Business Model Type

In product-oriented PSS-based business model types, the primary revenue stream comes from sales of high-grade products with a long useful life (e.g. the German company Miele's washing machines (Miele, 2017). Combining the product-oriented PSS-based business model type with the newly proposed definition of a circular business model results in a business model type we will call the *"Classic Long Life"* (Bakker, Den Hollander et al., 2014, p. 55) model. Building on the PSS definition by Boehm & Thomas (2013), the PSS description by Park et al. (2012) and the PSS classification by Tukker et al. (2006) presented earlier, we propose the following definition:

The *Classic Long Life business model type* embodies a product-oriented PSS-based business rationale that is designed to prevent and/or postpone and/or reverse obsolescence to a maximum extend, minimize 'leakage' and resort to the use of 'resources' in the process of creating, delivering and capturing value only when the options for using 'presources' have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible. Its primary revenue stream is generated from trading the right of ownership to tangible products with a potential for a long or extended product lifetime. In addition, it offers services that are needed during the use phase of the product.

As this business model type revolves primarily around transactions that are based on a transfer of ownership rights (Tukker, 2015, 2004; Reim et al., 2015; Bakker, Den Hollander et al., 2014; Malone et al., 2006; Tukker et al., 2006), where the total return, i.e., exchange value, on perceived use value created is captured in the instant of transaction (Malone et al., 2006; Bowman & Ambrosini, 2000, Herman, 1981), companies tend to lose economic control over the tangible product as soon as the transaction is completed (Malone et al., 2006). Although the Classic Long Life model can profit from a long lifetime potential by selling tangible products that are priced at a higher than average price point and have durability as a central part of their value proposition, the lack of economic control makes it less suitable for preserving and recapturing value over time. As a result, the manufacturer and/or provider need to capture enough exchange value from the one-time transfer of ownership rights transaction. The Classic Long Life model thus often revolves around offering high-grade products with a long life potential at a high price point in order to make this business model archetype commercially viable.

As a potential solution to the problem of losing economic control over their tangible products, Reim et al. (2015) -referencing Evans, Partidário & Lambert (2007), Tonelli, Taticchi & Starnini Sue (2009) and Tukker and Tischner (2006)- proposed the use of *"take-back agreements"* (Reim et al., 2015, p. 72) as a means for companies using the Classic Long Life model to regain economic control at the end of a product's use cycle and/or lifetime.

4.6.2 The Access Business Model Type

In a use-oriented PSS-based business model type (Reim et al., 2015, Tukker, 2015, 2004; Tukker et al., 2006), companies sell the right of use of a physical asset for a limited period of time (Reim et al, 2015; Tukker, 2015, 2004; Park et al., 2012; Malone et al., 2006; Tukker et al., 2006; Tukker, 2004). Zipcar (Zipcar, 2017), for instance, provides access to a car. The customer pays for access by the hour or day. And the Dutch start-up company Gerrard Street (Gerrard Street, 2017) offers modular, upgradable headphones for a small monthly fee. We will refer to the circular variety of this use-oriented PSS based business model archetype as the *"Access"* (Bakker, Den Hollander et al., 2014, p. 67) model. The Access model provides product access over time rather than ownership (Reim et al., 2015; Tukker, 2015, 2004; Park et al., 2012; Malone et al., 2006; Tukker, 2006). The main revenue stream for this circular business model type for preserving product integrity comes from payments for product access for a certain period of time (Reim et al., 2015; Tukker, 2015, 2004; (Bakker, Den Hollander et al., 2014; Park et al., 2012; Malone et al., 2006; Tukker, 2006).

Building on the PSS definition by Boehm & Thomas (2013), the PSS description by Park et al. (2012) and the PSS classification by Tukker et al. (2006) presented earlier, we propose the following definition:

The *Access business model type* embodies a use-oriented PSS-based business rationale that is designed to prevent and/or postpone and/or reverse obsolescence to a maximum extend, minimize 'leakage' and resort to the use of 'resources' in the process of creating, delivering and capturing value only when the options for using 'presources' have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible. Its primary revenue stream is generated from trading the right of use to tangible products with a potential for a long or extended product lifetime.

Access models are better at capturing value over time than Classic Long Life models, because the company *"keeps the ownership and often is responsible for maintenance, repair and control"* (Tukker et al., 2006, p. 33).

4.6.3 The Performance Business Model Type

In a result-oriented PSS-based business model archetype (Reim et al., 2015; Tukker, 2015, 2004; Tukker et al., 2006), companies sell the right to what an asset produces (Stahel, 2010; Malone et al., 2006). Companies like Flycleaners (2017) and Rinse (2017) for instance, offer on-demand dry cleaning and laundry services. Customers pay for clean clothes and this is what these companies produce (using industrial grade laundry machines). Building on Stahel (2010), we will refer to the circular variety of this result-oriented PSS business model archetype as the *"Performance"* (Bakker, Den Hollander et al., 2014, p. 71) model. The Performance model delivers product performance rather than the product itself (Stahel, 2010), whereby the result is not connected to a particular technological system or tangible product (Tukker at al., 2006). The primary revenue stream comes from payments received for performance delivered.

Building on the PSS definition by Boehm & Thomas (2013), the PSS description by Park et al. (2012) and the PSS classification by Tukker et al. (2006) presented earlier, we propose the following definition:

The *Performance model type* embodies a use-oriented PSS-based business rationale that is designed to prevent and/or postpone and/or reverse obsolescence to a maximum extend, minimize 'leakage' and resort to the use of 'resources' in the process of creating, delivering and capturing value only when the options for using 'presources' have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible. Its primary revenue stream is generated from trading the right of use to what a tangible product with a potential for a long or extended product lifetime produces.

Similar to Access models, Performance models are better at capturing value over time than Classic Long Life models, because the company retains economic control over the tangible products. In addition to being responsible for maintenance, repair and control, companies employing Performance models are also responsible for operating the tangible products (Bakker, Den Hollander et al., 2014; Tukker et al., 2006).

4.7 HYBRIDS AND GAP EXPLOITERS

4.7.1 Classic Long Life Hybrid and Access Hybrid

With regard to classification of business model types, Malone et al. (2006) remarked that *"at some suitably low unit of analysis (e.g., business unit), the classification should also not assign more than one business model to the same unit"* (p. 5). They did, however, *"not* *rule out higher units (e.g., firms) having multiple business models (e.g., because they have business units each with a different model)"* (Malone et al., 2006, p. 5). In some instances, such as Miele (2017a) with their *"Twin Dos"* (Miele, 2017a) washing machine types with dedicated detergent cartridges, Océ (2017) with its printers and supplies (toner and paper) (both companies were interviewed for this thesis and will be discussed in more detail section 5.5), Nespresso (2017) with its coffeemakers and capsules, Sony (PlayStation, 2017) with its PlayStation consoles and games, and Apple (2017) with its iOS devices and apps, business model types built around durable consumer goods are combined with business model types built around short(er) lived consumables to deliver a single product-service based value proposition (Park et al. 2012).

In the iPhone and App store example provided by Park et al. (2012), as much as three different business model types are used for different products that have specifically been designed to be used together. A transfer of right of ownership-based business model type is used for the tangible product, i.e., the iPhone. As the ownership rights to standard software intended for multiple users, such as Apps, are typically never transferred to the customer, a business model type whereby the customer pays for the right to use the software for a limited or unlimited period of time is used for the software (e.g. Apps). In addition to the above to business model types, the Apple App Store is a provider owned platform for transferring rights of use to both Apple software and software from other developers, Increasing the complexity of the business model type combination. In the latter instance, the business model type displays parallels to Malone et al.'s (2006) *"Physical Broker"* (p. 11) business model type, i.e., matching potential buyers and sellers of rights to a product. Because the product in this instance is software, it is, however, difficult to qualify the product as either tangible or intangible (Tukker, 2015).

From a product lifetime perspective, a second example is of particular interest in the context of the thesis. Park et al. (2012) listed the *"Woongin Coway water purifier"* (p. 539) as an instance of a business model type where, like in the previous example, either the rights of ownership or the rights of use to different kinds of products are traded. What sets this example apart from the previous example, however, is that the significant difference in product lifetime of the products involved (i.e., between the water purifier appliance itself and the filter that is to be replaced at regular intervals) is listed by Park et al. (2012) an important driver for resorting to the use of a product-service based business model type.

Although none of the above examples at the time of writing qualifies as a circular business model for preserving product integrity (as none of the example companies take back their products at the end of a use cycle), in theory both the Classic Long Life model and the Access model could be employed for the tangible durable consumer products in hybrid varieties that are not circular business models for preserving product integrity in the strictest sense of the term. Depending on whether the business model used for the short(er) lived consumables qualifies as a circular business model, these hybrids could qualify as circular business models. These hybrid models allow the capture of value over extended product lifetime to some extent. The hybrid model is built around a combination of a durable product and dedicated short-lived consumables. The main revenue stream in this business model archetype comes from the repeated transfer of ownership rights (Malone et al., 2006) of the fast-cycling, short-lived, consumable elements of the hybrid (Bakker, Den Hollander et al., 2014). In order to qualify as circular, the dedicated consumables, although by definition fast-cycling and short-lived, must also be designed for preserving product integrity and/or recycling. Hybrid models benefit indirectly from an extended product lifetime potential of the durable element of the hybrid as the extended product lifetime potential functions as an enabler for the primary revenue stream. The longer obsolescence of the durable product is postponed, or the easier it is to have obsolescence reversed, the longer the fast-cycling, short-lived, dedicated consumables can be sold the users of these durable products. However, once a product becomes obsolete, and the obsolescence cannot cost effectively and efficiently be reversed, the revenue stream generated by the sales of dedicated consumables for that product specimen comes to a halt. In addition, the user at that point in time is no longer 'locked-in', e.g. obliged to continue to use a particular brand of consumable to prevent switching cost. There now is a real risk that the user chooses a replacement product from another brand, either out of curiosity for the new or disappointment with the old.

4.7.2 Gap Exploiters

In an ideal, perfectly circular economy, companies built according to one of the three circular business model types for preserving product integrity defined in section 4.6 would preserve and/or (re)capture the added economic value from their products to a maximum extent at the end of their use cycles or lifetime. In the transition towards a perfectly circular economy or in a real-world, imperfect circular economy, however, not all lifetime based use value will be captured by the original equipment manufacturer (i.e., one of the circular business model types for preserving product integrity types identified in section 4.6), either because the remaining lifetime based use value is not recognized by the original equipment manufacturer or because the original equipment manufacturer has no commercial interested in the remaining lifetime based use value. This unrecognized and unrecovered use value gives rise to another business model type that we will refer to a *"Gap Exploiter"* (Bakker, Den Hollander et al., 2014, p. 63). Gap Exploiters have preserving product integrity, e.g. the postponement or reversal of obsolescence of a tangible product, at the core of their value proposition. As they do not design and manufacture the tangible product, these Gap Exploiters do not qualify as circular business model types for preserving product integrity and provide no differential input for the selection of design strategies for preserving product integrity. To belong to this new business model type, a business model should satisfy two conditions: Firstly, it should perceive and commercially exploit use value in an obsolete tangible product that, in its current state, has no perceived use value for its original manufacturer. We propose the term product lifetime value gap for this discrepancy in valuation and define it as follows:

A *product lifetime value gap* is the discrepancy in perception of use value of an obsolete tangible product between the OEM (original equipment manufacturer), who perceives the obsolete physical product as having no or negative value, and other parties in an economic system.

Secondly, it should have postponement or reversal of obsolescence of tangible products *manufactured by other firms* at the core of its value proposition.
The essential and discriminating element of the Gap Exploiter business model type is that it is built around the systematic procurement of presources with substantial but unrecognized use value at no, or token, exchange value. We propose the following definition:

A *Gap Exploiter business model type* is a product-, use-, or performance-oriented PSS-based

4

business model type based on the recognition and commercial exploitation of a product lifetime value gap in the life of another firm's product. It has the postponement or reversal of obsolescence of a tangible product as a core element of its value proposition.

In an ideal, perfectly circular economy, Gap Exploiters would no longer exist. They are discussed here, however, as in the transition towards a perfectly circular economy and in a real-world, imperfect, circular economy, their continued existence can help indicate and pinpoint where product lifetime-based use value is not captured by the original manufacturer, i.e., one of the circular business model types for preserving product integrity.

There are many examples of businesses of the Gap Exploiter type: Costco Photo Center (Costco, 2017) creates perceived use value by refilling used inkjet cartridges and captures value by reselling them at a profit but at a price that is lower than that of a similar new cartridge. USB typewriter (2017) provides kits, for converting many types of old typewriters into input devices for (tablet) computers, marketing them as *"a groundbreaking advancement in the field of obsolescence"* (USBtypewriter, 2017). Companies like Arrow Value Recovery (Arrow, 2017), that will be described in more detail as one of the companies that we interviewed for this thesis in sub section 5.5.5, and Leapp (2017) create perceived use value by collecting and refurbishing used computers or smartphones, considered obsolete by their former users (often businesses themselves) and that capture value by reselling them at a profit and with a limited warranty but at a price that is lower than similar grade new computer systems. Other examples are businesses like eBay (2017) and Marktplaats (2017) that provide a platform where products can be traded that have become obsolete to their current owners. In fact, every business, other than the original equipment manufacturer or those contractually linked to the original equipment manufacturer, that creates perceived use value by repairing tangible products that are broken (i.e., by reversing obsolescence), such as bicycles, electronic equipment, clothing or shoes can be considered to be of the Gap Exploiter type.

Figure 4.7.1: USB typewriter conversion kit. Image source: https://www.usbtypewriter.com/products/easy-conversion-kit#gs.vYi=lyo

Their existence has also been noted in recent literature, albeit with different terminology. Cohen & Kietzmann (2014) for example claimed that information and communication technologies have made the 'sharing economy' possible at scale, with platforms like Airbnb (Airbnb, 2017) and Uber (Uber, 2017) enabling people to rent out unused or underused assets such as rooms and car seats. Cohen & Kietzmann (2014) stated that *"...these developments have started to challenge traditional thinking about how resources can and should be offered..."* (p. 279). The Ellen MacArthur Foundation (EMF, 2015) as another example implicitly referring to Gap Exploiters, argued that we need *"growth within"* (p. 5), with a focus on *"getting much more value from the existing stock of products and materials"* (p. 14). In their report, they mentioned cars, food waste and unused office space as examples: *"the average European car is parked 92 percent of the time; 31 percent of food is wasted along the value chain; and the average European office is used only 35-50 percent of the time, even during working hours"* (p. 12). The Ellen MacArthur Foundation (EMF, 2015) claims that exploiting these unused and underused assets may deliver Europe up to 1.8 trillion Euro by 2030, whilst simultaneously creating leverage for a transition towards a circular economy.

In spite of these potentially very positive implications of the exploitation of product lifetime value gaps, there are drawbacks to Gap Exploiters as well, caused in particular by the unregulated nature of many Gap Exploiter businesses. Uber (Uber, 2017) for instance has been criticized for its cavalier attitude towards liability. *"If you summon a driver, you're putting your life in their hands. Is that driver insured properly? Does he have liability insurance?"* (Huffington Post, 2016). This Huffington Post blog post concerning Uber is but one indication that there are no straightforward answers. However, the economic growth displayed by Gap Exploiters can be taken as evidence that this business model archetype caters to a real (and sizeable) demand among consumers and, in many instances, has long surpassed eligibility for the 'niche market' qualification.

Despite their, sometimes subversive, nature, Gap Exploiters may well be here to stay, but original equipment manufacturers may also want to explore possibilities to capture value from and over the (extended) lifetime potential of their products themselves. By successfully exploiting 'left-over' perceived use value, i.e., product lifetime value gaps, Gap Exploiters in effect point the way towards a circular economy.

The most straightforward approach to act on the problem of 'left-over' value would perhaps be for an original equipment manufacturer to set up a strategic collaboration with a Gap Exploiter. We will not explore this direction further, however, as we consider it to lie outside the scope of this thesis. Another option for original equipment manufacturer would be to organize their own businesses differently. The next chapters examine and describe how this might possibly work, introducing the concept of 'managing obsolescence'. The purpose of 'managing obsolescence' is to enhance the economic and environmental efficiency of recovery processes in order to make it possible to optimize the total lifetime (including multiple use cycles) of tangible products in a circular economy.

4.8 DISCUSSION AND CONCLUSIONS

Chapter 4 provides an answer to sub-research question C: "What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?" After having introduced the business model as an accepted and widely used - though not unequivocally defined - construct with which the essential structure of any business, regardless of venture type, can be captured for analysis, classification and design of forms of doing business, we proposed a new definition for the concept of a circular business model: A *circular business model* describes how an organisation creates, delivers and captures value in a circular economic system, whereby the business rationale is designed in such a way that it preserves product integrity to a maximum extent, minimizes leakage and resorts to the use of resources in the process of creating, delivering and capturing value only when the options for using presources have been exhausted, in order to achieve the most complete cycling of materials within the larger economic system possible.

This new definition of a circular business model implies that circular business models for preserving product integrity must have control over the design (i.e., aesthetic and engineering specifications) of the tangible product component of the value proposition as this is the only way they can meet the requirement from the newly proposed circular business model definition of favouring the use of 'presources' over the use of 'resources' in the process of creating, delivering and capturing value, even when the actual manufacturing processes are outsourced. In addition to the ability to control the design of tangible products with a potential for an extended lifetime in conjunction with the services needed to realize that potential, circular business models for preserving product integrity need to be able to retain or regain economic control over (part of) their products, even after they have become obsolete (i.e., presources) as this allows them to prevent and/or postpone and/or reverse obsolescence and minimize 'leakage'. We also proposed the fraction of economic value added to (p)resources that is preserved over time as the new measure for business model circularity as it, in addition to taking into account the amount of (p)resources that is processed in (p) resource loops, takes into account how and when (i.e., how frequently) these (p)resources are processed as well.

Based on the findings from the current literature, we developed a new business model typology for circular business models for preserving product integrity. By combining business model types that according to the literature are able to create, deliver and capture value from extended product lifetime, i.e., PSS-based business models that have an intangible service component is an integral part of the value proposition built around a tangible product with a potential for an extended lifetime, with the newly proposed definition for a circular business model, we arrived at three circular business model types for preserving product integrity: The Classic Long Life model, the Access model and the Performance model. The circular business model types for preserving product integrity are ordered according to the relative share of the intangible, service, component in the value proposition built around a tangible product with a potential for an extended product lifetime. Increasing the share of the intangible, service, component in the value proposition built around a tangible product with a potential for an extended product lifetime can have two important effects. In addition to increasing a firm's (long and short term) profitability from a business-economic point of view, it can increase a firm's ability to retain or regain the economic control over its products and presources that is essential in a circular economy. Within or across companies, the three circular business model types for preserving product integrity for extended product lifetime from the typology can be combined into *coordinated closed loops*, either with each other or with more recycling oriented circular business models that create, deliver and capture value from short lived, non-durables, in the latter instance resulting in circular hybrid models.

In addition to the three circular business model types for preserving product integrity listed above, we introduced a fourth business model type that is able to create and capture value from preserving product integrity, i.e., the Gap Exploiter model, that does not qualify as a circular business model type as it does not have control over the design (i.e., aesthetic and engineering specifications) of the tangible product component of the value proposition. Gap Exploiters exploit product lifetime potential that was designed and manufactured into tangible products by other companies but not (re)captured by those other companies, either by ignorance or intent. Although the non-circular, Gap Exploiter business model archetype would not exist in an ideal and perfectly circular economy, it was presented nonetheless as it plays an important role in a real-world - and therefore imperfect – circular economy as well as in the transition towards a (more) circular economy. Gap Exploiters are important as they identify 'product lifetime value gaps', i.e., product lifetime potential that was designed and manufactured into tangible products but was left unexploited by the original equipment manufacturers. Gap Exploiters demonstrate how products and presources with remaining - but unrecognized or ignored - lifetime potential, that otherwise would be relegated prematurely to recycling processes destroying much of their embedded added economic value, can be recovered at product level in economically viable ways by cleverly transforming them into valuable propositions.

REFERENCES CHAPTER 4: CREATING AND CAPTURING VALUE FROM PRESERVING PRODUCT INTEGRITY

Accenture (2014). *Circular Advantage – Innovative Business Models and Technologies to Create Value in a World without Limits to Growth*. Retrieved June 29th, 2017 from https:// www.accenture.com/t20150523T053139__w__/us-en/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Strategy_6/Accenture-Circular-Advantage-Innovative-Business-Models-Technologies-Value-Growth.pdf#zoom=50.

Airbnb (2017). Airbnb company website: www.airbnb.com

Al-Debei, M., & Avison, D. (2010). Developing a unified framework of the business model concept. *European Journal of Information Systems, 19*, 359–376.

Apple (2017). Apple company website: www.apple.com

Armstrong, C. M., Niinimäki, K., Lang, C., & Kujala, S. (2016). A UseOriented Clothing Economy? Preliminary Affirmation for Sustainable Clothing Consumption Alternatives. *Sustainable Development*, *24*(1), 18-31.

Arrow (2017). Arrow Value Recovery company website: https://www.arrow.com/s-tech/

Ayres, R. U. (1994). Industrial metabolism: Theory and policy. In B. R. Allenby & D. Richards (Eds.), *The greening of industrial ecosystems* (pp. 23–37). Washington, DC: National Academies Press.

Baden-Fuller, C., & Haefliger, S. (2013). Business models and technological innovation. *Long range planning*, *46*(6), 419-426.

Bailey, K. D. (1994). *Typologies and taxonomies: an introduction to classification techniques* (Vol. 102). Sage.

Baines T. S., Lightfoot, H. W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J. R., Angus, J. P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., & Wilson, H. (2007). State-of-the-art in product-service systems. In *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 221(10)*, 1543 – 1552.

Bakker, C., den Hollander, M., Van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. Leidschendam, the Netherlands: TU Delft Library/ Marcel den Hollander IDCR.

Bakker, C.A., Wang, F., Huisman, J., & Den Hollander, M.C. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production 69*, 10-16.

Bartels, B., Ermel, U., Sandborn, P., Pecht, M. (2012). *Strategies to the Prediction, Mitigation and Management of Product Obsolescence*. Hoboken, NJ, USA: John Wiley & Sons Inc.

Bayus, B. L. (1991). The consumer durable replacement buyer. *Journal of Marketing 55*(1), 42–51.

Bellman, R., Clark, C., Malcolm, D.G., Craft, C.J., & Ricciardi, F.M. (1957). On the Construction of a Multi-Stage, Multi-Person Business Game. *Operations Research 5*(4), 469- 503.

Beuren, F. H., Ferreira, M. G. G., & Miguel, P. A. C. (2013). Product-service systems: a literature review on integrated products and services. *Journal of Cleaner Production*, *47*, 222-231.

Bressanelli, G., Perona, M., & Saccani, N. (2017). A new framework for assessing circular economy scenarios on durable consumer goods sectors. In *Proceedings of 4th International EurOMA Sustainable Operations and Supply Chains Forum*, Februari 26th-27th, 2017, Milan, Italy.

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van der Grinten, B. (2016). Product design and business model strategies for a circular economy, *Journal of Industrial **and Production Engineering, 33**(5), 308-320.*

Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of cleaner production*, *65*, 42-56.

Boehm, M., & Thomas, O. (2013). Looking beyond the rim of one's teacup: a multi- disciplinary literature review of Product-Service Systems in information systems, business management, and engineering & design. *Journal of Cleaner Production 51,* 245-260.

4

Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, *45*, 9-19.
Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. *British journal of management*, *11*(1), 1-15.
Brezet, J.C., Bijma, A.S., Ehrenfeld, J., & Silvester, S. (2001). The *Design of Eco-efficient Services.* Delft, the Netherlands: TU Delft for the Dutch Ministry of Environment.
Charter M., & Tischner U. (2001). Sustainable Solutions. Developing Products and Services for the Future. Sheffield, UK: Greenleaf.
Ciacci, L., Reck, B. K., Nassar, N. T., & Graedel. T. E. (2015). Lost by Design. *Environmental Science & Technology 49*(16), 9443– 9451.
Cohen, B., & Kietzmann, J. (2014). Ride on! Mobility business models for the sharing economy. *Organization & Environment*, *27*(3), 279-296.
Costco (2017). Costco Photo Center inkjet refill website: www.costcoinkjetrefill.com
Cusumano, M. A., Kahl, S. J., & Suarez, F. F. (2015). Services, industry evolution, and the competitive strategies of product firms. *Strategic management journal*, *36*(4), 559-575.
EBay (2017). Ebay company website: www.ebay.com
EMF (Ellen MacArthur Foundation) (2012). *Towards the Circular Economy Vol. 1 - An Economic and Business Rationale for an Accelerated Transition.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2013). *Towards the Circular Economy Vol. 2 - Opportunities for the Consumer Goods Sector.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2014). *Towards the Circular Economy Vol. 3 - Accelerating the scale-up across global supply chains*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2015). *Growth Within: a circular economy*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
Erler, S., & Rieger, E. (2016). Product Evolvement through Entirely Scheduled Lifecycles. *Procedia CIRP*, *48*, 79-83.
Evans, S., Partidário, P. J., & Lambert, J. (2007). Industrialization as a key element of sustainable product-service solutions. *International Journal of Production Research*, *45*(18-19), 4225-4246.
Flycleaners (2017). Flycleaners company website: www.flycleaners.com.
Forty, A. (1989). *Objects of Desire: Design from Wedgwood to IBM.* New York, NY, USA: Pantheon Books.
Geissdoerfer, M., Savaget, P., Bocken, N.M.P., & Hultink, E.J. (2016). The Circular Economy - A New Sustainability Paradigm? *Journal of Cleaner Production 143*, 757-768.
Gaiardelli, P., Resta, B., Martinez, V., Pinto, R., Albores, P. (2014). A classification model for Product-Service offerings. *Journal of Cleaner Production, 66*, 507-519.
Gebauer, H., Joncourt, S., & Saul, C. (2016). Services in product-oriented companies: past, present, and future. *Universia Business Review*, 49, 32-53.
Gerrard Street (2017). Gerrard Street company website: www.gerrardst.nl.
Graedel, T. E., & Allenby, B. R. (2003). *Industrial Ecology* (2nd ed.). Upper Saddle River, New Jersey, USA: Pearson Education, Inc.
Goedkoop, M. J., Van Halen, C. J., Te Riele, H. R., & Rommens, P. J. (1999). Product service systems, ecological and economic basics. *Report for Dutch Ministries of environment (VROM) and economic affairs (EZ)*, *36*(1), 1-122.
Govindan, K., Soleimani, H., Kannan, D. (2014). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research 240*, 603–626.
Grönroos, C. (1991). The marketing strategy continuum: towards a marketing concept for the 1990s. *Management decision*, *29*(1).
Grönroos, C. (1997). Valuedriven relational marketing: from products to resources and competencies. *Journal of marketing management*, *13*(5), 407-419.
Guide Jr., V. D. R., Harrison, T. P., & Van Wassenhove, L. N. (2003). The challenge of closed-loop supply chains. *Interfaces, 33*(6), 3-6.
Guide Jr., V. D. R., & Van Wassenhove, L. N. (2009). OR FORUM—The evolution of closed-loop supply chain research. *Operations research, 57*(1), 10-18.
Hagen-Zanker, J., & Mallett, R. (2013). *How to do a rigorous, evidence-focused literature review in international development, A Guidance Note.* London: Overseas Development Institute.
Hart, C. (2011). *Doing a literature review: Releasing the social science research imagination.* London, UK: SAGE.
Heiskanen, E. (1996). *Conditions for Product Life Extension.* National Consumer Research Centre Working Papers 23.
Hellström, M., Tsvetkova, A., Gustafsson, M. & Wikström, K. (2015). Collaboration mechanisms for business models in distributed energy ecosystems. *Journal of Cleaner Production, 102*, 226-236.
Herman, S. (1981). The uses and abuses of Roman law texts. *The American Journal of Comparative Law*, *29*(4), 671-690.
Hockerts, K., & Weaver, N. (2002). *Are Service Systems Worth Our Interest? Assessing the Eco-efficiency of Sustainable Service Systems.* INSEAD Working Document. Fontainebleau, France: INSEAD.
Huffington Post (2016). *7 Reasons I'm Not On Board With Uber*. Retrieved June 28th, 2017 from www.huffingtonpost.com/george-hobica/5-very-good-reasons-why-i_b_5406643.html.
Jacob, E. (2004). Classification and categorization: A difference that makes a difference. *Library Trends, 52*(3), 515–540.
James, P., Slob, A. & Nijhuis, L. (2001). *Environmental and Social Well Being in the New Economy: Sustainable services-An Innovation Workbook*. Bradford, UK: University of Bradford, TNO.
Kimbell, L. (2014). Marketing: connecting with People, Creating Value. In Stickdorn, M., Schneider, J., Andrews, K. & Lawrence, A. (Eds.), *This is Service Design Thinking - basics - tools - cases*. Amsterdam, the Netherlands: BIS Publishers.
Klang, D., Wallnöfer, M., & Hacklin, F. (2014). The Business Model Paradox: A systematic Review and Exploration of Antecedents. *International Journal of Management Reviews, 16*, 454-478.
Kohtamäki, M., Partanen, J., Parida, V., Wincent, J. (2013). Non-linear relationship between industrial service offering and sales growth: the moderating role of network capabilities. *Industrial Marketing Management, 42*(8), 1374-1385.
Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, *143*(C), 37-46.
Leapp (2017). Leapp company webite: https://leapp.nl
Lewandowski, M. (2016). Designing the Business Models for Circular Economy - Towards the Conceptual Framework. *Sustainability, 8*(43), 1-28.
Lifset, R. & Graedel, T. E. (2002). Industrial ecology: goals and definitions. In Ayres, R.U. (Ed.), *A handbook of industrial ecology* (pp. 3-15). Cheltenham, UK: Edward Elgar publishing.
Linder, M., & Williander, M. (2015). Circular business model innovation: inherent uncertainties. *Business Strategy and the Environment, 26*(2), 182-196.
Linton, D. & Jayaraman, V. (2005). A Framework for Identifying Differences and Similarities in the Managerial Competencies Associated with Different Modes of Product Life Extension. *International Journal of Production Research 43*(9), 1807-1829.
Lovelock, C., & Gummesson, E. (2004). Whither services marketing? In search of a new paradigm and fresh perspectives. *Journal of service research*, *7*(1), 20-41.
Malone, T. W., Weill, P., Lai, R. K., D'Urso, V. T., Herman, G., Apel, T. G., & Woerner, S. (2006). *Do some business models perform better than others*? Retrieved November 20th, 2017 from https://mpra.ub.uni-muenchen.de/4751/1/MPRA_paper_4751.pdf.
Mäkinen, S., & Seppänen, M. (2007). Assessing business model concepts with taxonomical research criteria: A preliminary study. *Management Research News*, *30*(10), 735-748.
Manzini, E. (1996). Sustainable Product-Services Development: Pioneer industries on Sustainable Service. Workshop organized by UNEP-WG-SPD in the INES Conference Challenges of Sustainable Development, August 22nd-25th, 1996. Amsterdam, the Netherlands
Manzini, E., & Vezzoli, C. (2002). *Product-Service-Systems and Sustainability, Opportunities for Sustainable Solutions.* Paris, France: Politecnico di Milano/UNEP.
Marktplaats (2017). Marktplaats company website: www.marktplaats.nl
Marradi, A. (1990). Classification, typology, taxonomy. *Quality & Quantity, 24*(2), 129-157.
Meijkamp, R. (1998). Changing consumer behaviour through ecoefficient services: an empirical study of car sharing in the Netherlands. *Business Strategy and the Environment*, *7*(4), 234-244.
Mentink, B. (2014). *Circular Business Model Innovation: A Process Framework and a Tool for Business Model Innovation in a Circular Economy* (Master's thesis). Delft University of Technology, Delft, the Netherlands & Leiden University, Leiden, The Netherlands.
Miele (2017a). Miele company website: www.miele.com/en/com/index.htm.
Moeller, A., & Rolf, A. (2001). Eco product lifecycle management. In *Environmentally Conscious Design and Inverse Manufacturing, 2001. Proceedings EcoDesign 2001: Second International Symposium on* (739-744). IEEE.
Mont, O. (2002). Clarifying the concept of product–service system. *Journal of Cleaner Production, 10*(3), 237-245.
Mont, O. (2004). *Product-Service Systems: Panacea or Myth?* (Doctoral thesis). Lund University, Lund, Sweden.
Mont, O., Dalhammar, C., & Jacobsson, N. (2006). A new business model for baby prams based on leasing and product remanufacturing. *Journal of Cleaner Production*, *14*(17), 1509-1518.
Nespresso (2017). Nespresso company website: www.nespresso.com
Océ (2017). Océ company website: www.oce.com.
Oliva, R., & Kallenberg, R. (2003). Managing the transition from products to services. *International journal of service industry management*, *14*(2), 160-172.

4

OPAi & MVO Nederland (2014). *Ondernemen in de circulaire economie, nieuwe verdienmodellen voor bedrijven en ondernemers.* Retrieved April 4th, 2017 from www.opai.eu/uploads/ondernemen-in-de-circulaire-economie.pdf.
Osterwalder, A. (2004). The Business Model Ontology—A proposition in a design science approach (Doctoral thesis). Université de Lausanne, Lausanne, France.
Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation*. Hoboken, NJ, USA: John Wiley & Sons.
Osterwalder, A., Pigneur, Y., & Tucci, C.L. (2005). Clarifying Business Models: Origins, Present, and Future of the Concept. *Communications of Association for Information Systems, 15*, 1-43.
Park, Y., Geum, Y., & Lee, H. (2012). Toward integration of products and services: Taxonomy and typology. *Journal of Engineering and Technology Management, 29*, 528-545.
PlayStation (2017). Sony PlayStation company website: www.playstation.com
Porter, M. E. (1980). *Competitive Strategy - Techniques for Analyzing Industries and Competitors. New* York, NY, USA: The Free Press.
Porter, M.E. (1996). What is Strategy? *Harvard Business Review*, November-December issue.
Porter, M.E. (1998). *Competitive Advantage - Creating and Sustaining Superior Performance*. **New York, NY, USA: Free Press.**
Prendeville, S., & Bocken, N. (2017). Design for remanufacturing and circular business models. In *Sustainability Through Innovation in Product Life Cycle Design* (pp. 269-283). Springer Singapore.
Reim, W., Parida, V. & Örtqvist, D. (2015). Product-Service Systems (PSS) business models and tactics - a systematic literature review. *Journal of Cleaner Production, 97*, 61-75.
Richardson, J. (2008). The business model: an integrative framework for strategy execution. *Strategic Change, 17*(5-6), 133-144.
Rinse (2017). Rinse company website: www.rinse.com.
Rizos, V., Behrens, A., Van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M. & Topi, C. (2016). Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers. Sustainability 8(11) 1212: 1-18.
Saxena, K. B. C., Deodhar, S. J., & Ruohonen, M. (2017). The Business Model Concept and its Use. In *Business Models Innovation in Software Product Industry, 13-34*. India: Springer India.
Scott, J. T. (2015). The Sustainable Business - a Practitioner's Guide to Achieving Long-Term Profitability and Competitiveness (2nd ed.). Sheffield, UK: Greenleaf Publishing**.**
Shafer, S., Smith, H., & Linder, J. (2005). The power of business model. *Business Horizon, 48*(3), 199–207.
Smith, K. B. (2002). Typologies, taxonomies, and the benefits of policy classification. *Policy Studies Journal*, *30*(3), 379-395.
Stahel, W. R. (2010). *The Performance Economy* (2nd ed.), Hampshire, UK: Palgrave Macmillan Hampshire.
Stout, L. (2017). *Corporations Don't Have to Maximize Profits*. Retrieved May 10th, 2017 from www.nytimes.com/roomfordebate/2015/04/16/what-are-corporations-obligations-to-shareholders/corporations-dont-have-to-maximize-profits.
Sundin, E., & Bras, B. (2005). Making functional sales environmentally and economically beneficial through product remanufacturing. *Journal of Cleaner Production, 13(9),* 913-925.
Teece, D. J. (2010). Business models, business strategy and innovation. *Long range planning*, *43*(2), 172-194.
Tischner, U., Schminke, E., Rubik, F., & Prösler, M. (2000). *How to do EcoDesign? A guide for environmentally and economically sound Design.* In collaboration with B. Dietz, S. Maßelter & B. Hirschl, edited by the German Federal Environmental Agency. Frankfurt am Main, Germany: Verlag form Praxis.
Tonelli, F. L., Taticchi, P. A., & Starnini Sue, E. (2009). A framework for assessment and implementation of product-service systems strategies: learning from an action research in the health-care sector. *WSEAS Transaction on Business and Economics*, *6*(7), 303-319.
Tsvetkova, A. & Gustafsson, M. (2012). Business models for industrial ecosystems: a modular approach. *Journal of Cleaner Production, 29*, 246-254.
Tukker, A. (2004). Eight Types of Product– Service System: Eight Ways to Sustainability? Experiences from Suspronet. *Business Strategy and the Environment 13*, 246–260.
Tukker, A. (2015). Product services for a resource-efficient and circular economy - a review. *Journal of Cleaner Production, 97*, 76-91.
Tukker, A., & Tischer, U. (Eds.) (2006). New Business for Old Europe - Product-service development, competitiveness and sustainability. Sheffield, UK: Greenleaf Publishing Ltd.
Tukker, A., & Van den Berg, C. (2006). Product-services and competitiveness. In Tukker, A., & Tischner, U., (Eds.), *New Business for Old Europe - Product-service development, competitiveness and sustainability.* Sheffield, UK: Greenleaf Publishing Ltd.
Tukker, A., Van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In Tukker, A., & Tischner, U., (Eds.), *New Business for Old Europe - Product-service development, competitiveness and sustainability*. Sheffield, UK: Greenleaf Publishing Ltd.
Uber (2017). Uber company website: https://www/uber/com
USBtypewriter (2017). USBtypewriter company website: https://www.usbtypewriter.com/products/easy-conversion-kit#gs.vYi=Iyo
Van Ostaeyen, J., Van Horenbeek, A., Pintelon, L., & Duflou, J. R. (2013). A refined typology of product-service systems based on functional hierarchy modelling. *Journal of Cleaner Production, 51*, 261-276
Van Renswoude, K., Wolde, A. T., Joustra, D. J. (2015). Circular Business Models. Part 1: An introduction to IMSA's Circular Business Model Scan. Retrieved April 4th, 2017 from https://groenomstilling.erhvervsstyrelsen.dk/sites/default/files/media/imsa_circular_business_models_-_april_2015_-_part_1.pdf.
Van Nes, N., & Cramer, J. (2005). Influencing Product Lifetime through Product Design. *Business Strategy and the Environment 14*, 286-299.
Vargo, S. L., & Lusch, R. F. (2004). The four service marketing myths: remnants of a goods-based, manufacturing model. *Journal of service research*, *6*(4), 324-335.
Wirtz, B. W., Göttel, V. & Daiser, P. (2016). Business Model Innovation: Development, Concept and Future Research Directions. *Journal of Business Models, 4*(1), 1-28.
Wirtz, B.W., Pistoia, A., Ullrich, S., & Göttel, V. (2016). Business Models: Origin, Development and Future Research Perspectives. *Long Range Planning 49*, 36-54.
WRAP (Waste and Resources Action Programme) (2017). Circular economy definition. Retrieved March 29th, 2017 from www.wrap.org.uk/about-us/about/wrap-and-circular-economy.
Zeithaml, V. A., Parasuraman, A., & Berry, L. L. (1985). Problems and strategies in services marketing. *The Journal of Marketing*, 33-46.
Zipcar (2017). Zipcar company website: www.zipcar.com
Zott, C., & Amit, R. (2010). Business model design: an activity system perspective. *Long range planning*, *43*(2), 216-226.
Zott, C., Amit, R., & Massa, L. (2011). The business model: Recent developments and future research. *Journal of Management 37*(4), 1019-1042.

4

5

MANAGING OBSOLESCENCE

What guiding principles and management strategies can businesses use when creating, delivering and capturing value from long and extended product lifetimes in a circular economy?

5.1 INTRODUCTION

Having defined three types of circular business models for preserving product integrity in chapter 4, chapter 5 now aims to provide an answer to sub-research question D: "What guiding principles and management strategies can businesses use when creating, delivering and capturing value from long and extended product lifetimes in a circular economy?" The objective of chapter 5 is to identify and develop guiding principles and management strategies for circular business models for preserving product integrity.

To provide guidance to industrial designers in deciding on what design strategy or combination of design strategies to best apply when designing products for a particular type of circular business model for preserving product integrity, chapter 5 and 6 will go progressively deeper into the matter of determining which design strategy or combination of design strategies can be expected to be successful from both an environmental and an economic perspective when used in conjunction with a particular circular business model for preserving product integrity. Chapter 5 sets out to identify the goals and barriers to achieving those goals for circular business model for preserving product integrity and to identify and develop management strategies for achieving those goals, as these provide the business context for design for preserving product integrity in circular business model for preserving product integrity.

To this end, chapter 5 begins by reviewing the literature from the fields of (sustainable) design and the business sciences. Next, chapter 5 presents the results from interviews with representatives from seven companies that presently create and capture value from products with a long or extended product lifetime. Based on the findings from the literature and the insights gained from the company interviews, chapter 5 proposes a new management strategy for circular business model for preserving product integrity to overcome, or mitigate the effects of, the challenges as they emerged from the interviews and the review of the literature.

5.2 METHODOLOGY

Gathering and Processing Data – Review of the Literature
A literature review was done for chapter 5 in order to identify the goals and barriers for circular business model for preserving product integrity and identify and develop management strategies for achieving those goals. The review of the literature is based on the procedures described by Hagen-Zanker and Mallet (2013) as discussed in section 1.5 Research Design. The research presented in chapter 5 draws predominantly from scientific publications but also grey literature from the fields of the business sciences and (sustainable) product design. The initial body of literature, limited to documentary sources in the English, Dutch or German language but without limits to publication date, is compiled from the search results returned by Google Scholar, for search terms related to sustainable product design, eco-design, and circular economy. The initial list of search terms consists of (combinations of): closed loop supply system*, planned obsolescence, product lifetime*, reverse logistics. Using snowballing, new keywords that emerge are added to the initial set.

The results of the searches were scan-read to determine, based on the over 20 years of hands-on experience of the author in the fields of commercial industrial design and sustainable design and erring on the side of caution, whether they pertained to product design, product design for extended lifetimes, product lifetime, circular economy, sustainability and business in a manner that was potentially relevant to the topic of the research. Clearly irrelevant results, for example highly technical econometric or computing related papers, were discarded before storing the results in a software-based retrieval system and assigning (additional) keywords to them for later reference.

In total, over 100 articles are studied in detail in order to gain a deeper understanding of the matter at hand, identify the *seed literature* (works of research on the topic considered as fundamental in the specific field), to detect similarities, discrepancies, inconsistencies, and/or contradictions (Hart 2011).

Gathering and Processing Data - Company Interviews and Visits

Empirical data was gathered from seven companies. The seven companies were selected based on 1) the results of desk research, 2) the responses to an inquiry among research colleagues at the department of Design for Sustainability of the Delft University of Technology and 3) from the list of companies participating in the ResCom (ResCom, 2017) (the acronym stands for RESource Conservative Manufacturing) research project that the author of the thesis was part of. The criteria for company selection were: 1) companies need to create, deliver and capture value from durable products with a potential for long and/or extended product lifetime, 2) company representatives need to be willing to share information and discuss the workings of the company with regard to manufacturing and marketing products with a potential for long and/or extended product lifetime 3) companies will allow the data acquired from the inquiry to be used for purpose of the research, 4) the inquiries can take place in Europe and 5) interviews can take place in the Dutch, German or English language.

Data was gathered in two different ways: 1) through single session interviews with one or two company representatives, 2) through a number of interviews with/presentations from company representatives during three-day company visits. All interviews and presentations took place at the respective companies. The five single-session interviews were with representatives from Miele, Eastpak, Océ, BMA Ergonomics and Arrow Value Recovery. The three-day company visits were with Loewe and Tedrive and were conducted as part of the ResCom project. All sessions were recorded using a voice recorder (after asking for and obtaining permission from the participants). The recordings from the single session interviews were fully transcribed. The recordings from the sessions that took place over multiple days, however, were summarized in session reports.

A semi-structured approach was chosen in both types of inquiry for three reasons. The first is that the research presented in this thesis is explorative and the semi-structured interview approach allows for capturing additional information that might prove relevant, potentially contributing to new and unexpected insights. The second reason is that, as all interviewees are business professionals in managerial positions, the opportunities to go deeper into particular remarks during follow-up interviews at a later time were limited. Lastly, with over 20-years of hands-on experience of the author in commercial industrial design, the semi-structured interview approach allowed for the quick creation of rapport (DiCicco-Bloom & Crabtree, 2006) and instant exploration of emerging, but related, topics.

During the single session interviews, a diagram (see Appendix F: Company Interview Guide Diagram) was used to provide structure for the initial questions. The diagram was based on the nine business model building blocks as proposed by Osterwalder and Pigneur (2010) and an early, working version of the set of interventions for product lifetime extension, that was later developed in the typology of interventions for preserving product integrity presented in chapter 2 in order to help focus the interview on issues pertaining to preserving product integrity and ensure that all nine business model areas were covered.

A similar device was not required (but nonetheless kept as a backup for personal use) during the visits of the companies as part of the ResCom project as these companies had joined the ResCom project with the explicit goal of addressing, sharing and potentially improving the way in which they managed issues pertaining to preserving product integrity.

The data from the single session interviews and three-day company visits was analysed and compared through repetitive, reflective immersion (DiCicco-Bloom & Crabtree, 2006) in the recordings, transcriptions and summaries, whereby the experience from the author in commercial industrial design mentioned earlier provided the *"strong theoretical background"* (DiCicco-Bloom & Crabtree, 2006, p. 40) that is a prerequisite when applying this *"immersion/crystallisation"* (DiCicco-Bloom & Crabtree, p. 40) approach.

In the presentation of the results in section 5.5, the empirical data from the interviews and visits is complemented with (referenced) data from the (grey) literature about the company (e.g., history, ownership, size and turnover) to provide a richer context.

5.3 CHALLENGES FOR CIRCULAR BUSINESS MODELS FOR PRESERVING PRODUCT INTEGRITY: A REVIEW OF THE LITERATURE

5.3.1 Introduction

This chapter looks at business-economic goals and challenges particular to circular business models. The current section will therefore not discuss goals (and challenges) that are valid for both linear and circular models, such as (challenges to achieving) short-term profit and long-term continuity (Stout, 2017; Tukker et al., 2006; Heiskanen, 1996). As we discussed in chapter 2, in a closed loop, circular, economy, the short and long-term business-economic goals have to be achieved in a context that - by definition - no longer allows any obsolete products and/or their constituent materials to be discarded as 'waste'. As a consequence of this requirement, preserving economic value added to (p)resources to a maximum extent is mandatory for all products rather than optional. The impact this absolute requirement will have on the ability of businesses to create profits depends firstly on the extent to which the conventions for economic valuation are capable of valuing environmental costs and benefits and secondly on how successful businesses are in integrating the new requirement into their business-economic strategies. Although there are some indications that the situation is slowly changing (e.g. Gómez-Baggethun & Ruiz-Pérez, 2011; Daily, 2000), our present conventions for economic valuation are generally unable to capture environmental benefits and damages in economic terms (Ayres & Ayres, 1996; Hanemann, 1994; Sirkin & Ten Houten, 1994). Should these conventions remain unchanged, the viability and success of the circular economy concept will largely depend on how well businesses will be able to align their business-economic (including product design) strategies with the new environmental requirement.

As mentioned in chapter 1, for most businesses operating in a linear economic context, what happens to their products after the moment of sale is (with the exception of brand reputation considerations and legal requirements) of little commercial interest and largely outside their span of control (Erler & Rieger, 2016; Malone et al., 2006). The circular economy requirement of closed material loops without waste implies that circular business models for preserving product integrity need to effectively and efficiently manage - without gaps or exceptions - what happens with products during and after their entire (sequence of) product use cycles.

At present, however, the literature on circular business models does not discuss the particular challenges for circular business models resulting from that absolute obligation, nor does it elaborate on the implications for industrial designers and business professionals.

It is therefore necessary that the challenges for circular business models from the current literature on circular business models are reconsidered and refined. To this end, the remainder of this section will start with a review the wider (i.e., not specifically focused on circular business models) literature pertaining to preserving added economic value (such as the literature on closed-loop supply chains from the domain of the business sciences) to gain insights as to how maximum business model circularity (see section 4.4) may best be achieved and what potential barriers to achieving maximum business model circularity exist.

5.3.2 Barriers to Implementing the Inertia Principle in Closed-Loop Recovery Processes

Although a circular economy as a whole strives to mimic a closed loop, type III ecology (Graedel & Allenby, 2003; Lifset & Graedel, 2002) (see section 1.2) as closely as possible, it is made up of both 'open-loop recovery processes' and 'closed-loop recovery processes' (Graedel & Allenby, 2003; Keoleian & Menery, 1993). In open-loop recovery processes, presources are turned into other types of products than the ones they came from. As all product integrity is destroyed in open-loop recovery processes, open-loop recovery processes are confined to the semi-finished product or 'material' level. Open-loop recovery processes require complete dismantling of products, and consequently a high amount of the added economic value, i.e., labour that was required for production of the original product (Fine & Saad-Filho, 2016, see Appendix B.1: Value and Profit), is lost (Van Weelden, Mugge & Bakker, 2016).

In closed-loop recovery processes, e.g., closed-loop supply chains (Guide Jr. & Van Wassenhove, 2009), presources are (re)turned into the same products as they came from, sometimes even many times over (Graedel & Allenby, 2003; Guide Jr., 2000; Keoleian & Menery, 1993).

In closed-loop recovery processes product integrity is retained to a greater or lesser degree, depending on the type of intervention for preserving product integrity that is applied. Closed-loop recovery processes often do not require complete dismantling of products, and consequently a higher amount added economic value, i.e., labour that was required for production of the original product (Fine & Saad-Filho, 2016, see section 4.2.1), is preserved than is possible through open-loop recovery processes (Van Weelden et al., 2016). Closed-loop recovery processes seek *"to close the materials-use cycle by using repair and remanufacture operations to extend a product's life. Recycling is used only when no value-added remains"* (Guide, Jayaraman, Srivastava & Benton, 2000, p. 126).

The current literature is clear on how, in theory, these two types of recovery loops should be applied in order to maximize business model circularity in theory. According to Stahel's (2010) Inertia Principle, the economic value added to (p)resources through the various processes of turning them into tangible products is best preserved when over time *"only the smallest possible part"* (Stahel, 2010, p. 195) of a tangible product is replaced or treated *"in order to maintain the existing economic value of the technical system"* (Stahel, 2010, p. 195). In chapter 2 we have used this principle to determine the order of the interventions in our newly developed typology for preserving product integrity. This general preference for preserving product integrity over recycling is consistently expressed elsewhere in the (grey and scientific) literature (e.g., Van Weelden et al., 2016; EMF, 2015; 2014; 2013; 2012; Hatcher, Ijomah & Windmill, 2011; Guide Jr., 2000; Guide Jr. & Srivastava, 1998; Oakdene Hollins Ltd., 2007; King & Burgess, 2005). Although the Inertia Principle appears straightforward enough in theory, the literature shows that realizing maximum business model circularity by implementation of the Inertia Principle in practice can be rather more complex. For one, application of the Inertia Principle results in environmental impact. Given that, as observed by Heiskanen (1996) in 'Conditions for Product Life Extension', the total environmental impact of a product depends on *"the amount of natural resources used along the product lifecycle"* (p. 2) and *"the nature of the interventions and material flows"* (p. 2) associated with that product over its lifetime, these actions and interventions for preserving product integrity, if not taken into account properly, could reduce or even negate any potential positive environmental effects of preserving added economic value (i.e., lifetime extension at product and/or material level) (Bakker, Wang et al., 2014; Van Nes & Cramer, 2005; Heiskanen, 1996). The current section therefore continues with a review of the wider literature in search of potential barriers to the consistent implementation of the Inertia Principle and achieving maximum business model circularity.

Barrier 1: The Unpredictability of the Quantity and Quality of the Return Flow of Obsolete Products

Linder & Williander (2015) observed that many of the practical problems experienced by linear business models that employ closed-loop supply chains (Guide Jr. & Van Wassenhove, 2009) are similar to those experienced by circular business models attempting to maximize business model circularity, as both *"always involve recycling, remanufacturing, reuse or one of their sibling activities (e.g. refurbishment, renovation, repair"* (p. 2). This observed similarity between the two settings is in line with Guide Jr, Kraus & Srivastava (1997), who - in a linear economic context - described *"recoverable product environments"* (p. 187) such as closed loop supply chains, as *"part of strategies to increase product life and prevention of waste through repair and remanufacturing"* (p. 187).

Research from the domain of the business sciences on closed-loop supply chains, or recoverable product environments, consistently shows that at present there is a great variation in the number of use cycles, and the number and type of interventions that are actually executed over the lifecycle of the tangible product (e.g. Linder & Williander, 2015; Guide Jr., 2000; Guide Jr. et al., 2000; Guide Jr. & Srivastava, 1998; Guide Jr. et al., 1997; Fleischmann et al., 1997) These random fluctuations in the flow of obsolete products through recovery loops make it difficult to consistently implement the Inertia Principle.

In a closed-loop supply chain, obsolete products are brought back from customers into the manufacturing process for recovery of *"added value by reusing the entire product, and/or some of its modules, components, and parts"* (Guide Jr. & Van Wassenhove, 2009, p. 10). The returns have become obsolete for different reasons and come at different times, from different sources and different stages of the product life cycle (e.g., Guide Jr. & Van Wassenhove, 2009; Guide Jr. et al., 2003; Guide Jr., 2000; Thierry, Salomon, Van Nunen & Van Wassenhove, 1995) As a result, the age and condition of the returns often vary greatly, even when only a single product model is considered, ranging from 'new' and 'like new' for the returns from manufacturing and early returns from purchases by users, to 'worn out', 'broken' and 'damaged' for the end-of-use-cycle returns from users (Guide Jr., 2000; Guide Jr. et al., 2003; Guide Jr. & Van Wassenhove, 2005).

5

The two main reasons these fluctuations cause such problems for manufacturers are that 1) their inherent uncertainty makes matching supply and demand very difficult (Guide Jr. & Van Wassenhove, 2005; Jayaraman, 2005) and 2) *"each type of return requires a reverse supply chain appropriate to the characteristics of the returned products to optimize value recovery"* (Guide Jr. et al., 2003, p. 3). As a result, the interventions, the amount of added economic value preserved, and the environmental impact generated in the value recovery process, will be different for each of these different loops (Jayaraman, 2005).
Research in the business sciences on recoverable product environments or closed-loop supply chains has so far devoted only limited attention to the design of the products that are subject of the various recovery processes (Atasu, Guide Jr., Van Wassenhove, 2008, Navin-Chandra, 1994). Most of this research is limited to process and geometry related issues like ease of (dis)assembly and part or material separation (Atasu et al., 2008, Navin-Chandra, 1994). The unpredictable variations in the age, condition and volume of the flow of returns, however, affects and is affected by the design of the products. With rising uncertainty, it becomes increasingly difficult to determine the amount and type of potential for preserving product integrity that should be designed into a product.

Causes for the Unpredictability of the Quantity and Quality of the Flow of Obsolete Products
The unpredictability of the quantity and quality of the flow of obsolete products can be seen as the compound result of a lack of control of manufacturers over two different aspects of the flow.

Firstly, the currently widespread business practice transferring the right of ownership rights to a product to the customer at the moment of transaction (Malone et al., 2006; Herman, 1981) (see chapter 4) makes it difficult for manufacturers to get products back once they have reached the end of a use cycle. To solve this problem in product-oriented PSS-based business models, take-back agreements (i.e., agreements to transfer ownership back to the supplier at the end of a use cycle) are sometimes made at the start of each new use cycle (Reim et al., 2015; Tonelli et al., 2009; Evans et al., 2007; Tukker & Tischner, 2006).

Secondly, the onset of obsolescence is difficult to predict and control. Perhaps the most obvious reason for this is the inherently subjective nature of obsolescence. Another reason, however, lies in the difficulty of accurately predicting *"path*[s] *of technological innovation"* (Sood, James, Tellis & Zhu, 2012, p. 964), i.e., the rates and types of changes in the technologies that form the basis for many products and whether and at what pace they will be adopted (Kim, 2003). Although there is general agreement in the literature that these rates and types of changes vary between markets and even between technologies in a single market (e.g. Sood et al., 2012, prediction is difficult as at present there is no *"single, strong, unified theory of technological evolution"* (Sood & Tellis, 2005, p. 152) for capturing the technology life cycle (TLC) Taylor & Taylor, 2012) (see Appendix E: The Product Life Cycle, Industry Life Cycle).

As discussed in chapter 2, a product becomes obsolete if it no longer is considered useful or significant by its user (Burns, 2010). In many, but not all, instances the onset of obsolescence is triggered by an outside event at the product and/or system side (Den Hollander, Bakker & Hultink, 2017; Box, 1983), such as a real or perceived (e.g. in comparison with a newly introduced product) change in functionality (e.g. Burns, 2010; Cooper, 2010; Box, 1983) or a real or perceived (e.g. in comparison with a newly introduced product) change in aesthetic aspects (e.g. Burns, 2010; Van Nes & Cramer, 2005; Van Nes, 2003).

The review of the literature, as well as the company interviews, such as that of Arrow Value Recovery (Arrow, 2017), that will be presented shortly in section 5.5, make clear that the unpredictable variations in the age, condition and volume of the flow of returns already pose a major problem to the management of recoverable product environments in a linear economic context. The problem, however, is even worse in a circular economy. In a circular economy, there is an increased need to control the flow of obsolete products because of the requirement for circular business models for preserving product integrity to preserve the added economic value for *all* products and (p)resources to a maximum extent. Erler and Rieger (2016) for example observed that *"with the shift toward new operating models, such as the subscription model"* (p. 80), and other business models based on the circular business model types for preserving product integrity as presented in section 4.6, *"the demand for controlling the overall lifecycle arises"* (p. 80). Terzi, Bouras, Dutta, Garetti and Kiritsis (2010), referencing Ferguson and Browne (2001), predicted that in the future there will be a shift in the relative *"importance of the product's lifecycle stages in the company value creation"* (p. 383) as illustrated in figure 5.3.1.

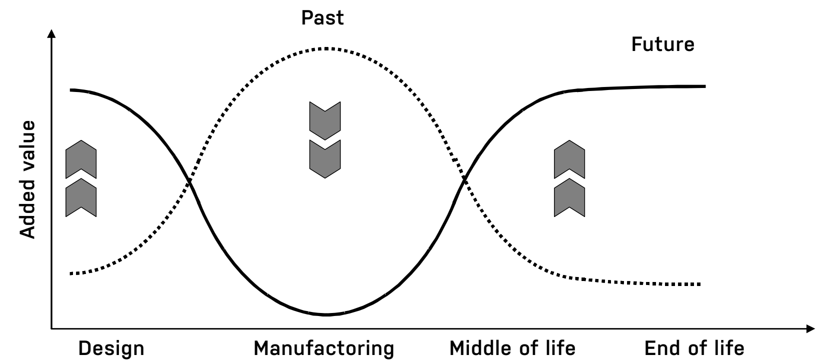


Figure 5.3.1: Shift of relative importance of the various product's lifecycle stages in the company value creation, reproduced from Terzi et al., 2010, p. 383.

Thirdly, when reviewed with the absolute environmental goal of a circular economy in mind, the literature from the field of sustainable product design yields yet another potential trigger for the onset of obsolescence that is unique to a circular economy context. There currently is general agreement among researchers (e.g. Bakker, Wang et al., 2014; Kim et al. 2006; Van Nes & Cramer, 2005; Van Nes, Cramer & Stevels, 1999) that the optimal moment for replacement of a tangible product from an environmental perspective is *"the point in time where the environmental impacts that arise from using a product equal the embedded impacts of a (more energy efficient) replacement product"* (Bakker, Wang et al., 2014, p. 12). When we consider the circular economy from an absolute perspective, this finding implies that an existing product would have to be replaced - and therefore would become obsolete - once such a (more energy efficient) replacement product becomes available on the market, whereas in the relative context of a linear economy, continued use of the original product would be allowed, although perhaps not preferred. Such an 'obsolescence triggering' appearance of a (more energy efficient) replacement product in the market could for example be the result of an introduction of a new and innovative product by a competitor.

5

Barrier 2: Misalignment between Actions in Support of Environmental Goals and Those in Support of Economic Goals

Conflicts between the actions required in support of preserving product integrity and those required in support of creating perceived use value and customer surplus (Bowman & Ambrosini, 2000) (see Appendix B.1: Value and Profit), pose a second barrier to maximizing business model circularity. Although all work on (p)resources changes the use value of those (p)resources, not all changes in use value amount to changes in perceived use value (Anderson, Lin, Simester & Tucker, 2015; Bowman & Ambrosini, 2000) (see Appendix B.1: Value and Profit). In a business context, all actions that change (p)resource use value without adding perceived used value are generally perceived as cost and therefore are avoided whenever possible. If actions for preserving product integrity do not create perceived value and can be avoided, a business will therefore most likely do so. For example, the use of relatively costly or labour-intensive methods of assembling a product (such as screwing instead of gluing a product together), that can aid future maintenance, repair, remanufacture and recycling will be avoided if this does not result in the creation of additional perceived used value and capture of additional economic value.

Causes of Misalignment between Actions in Support of Environmental and in Support of Economic Goals

The literature provides two causes for potential misalignments, between the actions required in support of preserving product integrity and those required in support of creating perceived use value.

The first cause for potential misalignment lies in the conventions for economical valuation (Ayres & Ayres, 1996; Hanemann, 1994; Sirkin & Ten Houten, 1994) that are in place at a particular time. The current conventions for economic valuation in our linear economy are unable to capture environmental benefits and damages in economic terms, and therefore increase the difficulty of aligning actions required for achieving economic and environmental business objectives. Some business models, such as those of the Sell More, Sell Faster (see chapter 4) business model type that is built around the transfer of ownership and maximizing the number of such sales transactions per unit of time, often only make sense from an economic business perspective in a context where the full extent of the environmental damage it causes is not expressed in economic terms and therefore is not part of the company's profit and loss statement.

The second cause for potential misalignment lies in the particulars of the business model instance as it is used by a company (Rose, 2000). According to Rose (2000), *"the mismatch between recommended end-of-life strategy and the actual end-of-life treatment is due to: having inefficiencies in the end-of-life systems, developing end-of-life systems for inappropriate end-of-life strategies, and lacking incentives for participation and innovation towards higher levels of reuse"* (p. 104).

With the introduction of the three circular business model types for preserving product integrity in chapter 4, a significant step forward has already been made in addressing the second barrier. Because contrary to the 'Sell More, Sell Faster' business model type, these circular business model types for preserving product integrity are able to create and capture value from preserving product integrity, they open up the possibility of bringing the actions required in support of preserving product integrity and those required in support of creating perceived use value and customer surplus (Bowman & Ambrosini, 2000) into alignment. Which regard to which combinations of circular business models for preserving product integrity and interventions for preserving product integrity actually are able do so, however, much is still unknown. The properties of the various circular business model types for preserving product integrity and the intrinsic nature of some of the interventions for preserving product integrity suggest, however, that some combinations are less likely to be successful in creating perceived use value than others. The rational view of the tangible product as a means of production that characterizes the Performance business mode type for example, seems to make functionally oriented design strategies like design for physical durability, design for maintenance or design for repair more likely candidates than a strategy like design for emotional durability that is aimed at creating a long-term emotional bond between the tangible product and its user.

It follows that in order to make product lifetime extension in circular business models for preserving product integrity effective and efficient, and perhaps even to make it economically feasible at all, efforts should be made surmount the barriers 1, i.e., control and reduce the random fluctuations in the flow of obsolete products and barrier 2, i.e., find a way to align actions in support of environmental goals with those in support of economic goals.

The next section will present (the development) of a potential solution for controlling and reducing the random fluctuations in the flow of obsolete products.

5.4 APPROACHES TO AFFECT OR CONTROL THE FLOW OF OBSOLETE PRODUCTS: A REVIEW OF THE LITERATURE

This section discusses existing approaches to affect or control the quality and/or quantity of the flow of obsolete products as can be found in the current literature. They are presented in the sub-sections below order in which they were first developed and started to emerge in the (grey) literature.

5

5.4.1 Planned Obsolescence

In 1954, 22 years after the term was first introduced by Bernard London (Burns, 2010; Slade, 2007) industrial designer Brooks Stevens popularized the concept of 'planned obsolescence' among industry after having redefined it as *"instilling in the buyer the desire to own something a little newer, a little better, a little sooner than is necessary"* (Adamson, 2003, p. 4). A little over 60 years later - and wiser as to the societal and environmental consequences of the concept - the French Assemblée Nationale defined *"l'obsolescence programmée"* (Assemblée Nationale, 2015) or 'planned obsolescence' rather more directly as *"l'ensemble des techniques par lesquelles un metteur sur le marché vise à réduire délibérément la durée de vie d'un produit pour en augmenter le taux de remplacement"* (Assemblée Nationale, 2015) which translates to English as 'the group of techniques through which one who places a product on the market plans to deliberately shorten the lifetime of a product in order to increase its replacement rate. With *planned obsolescence*, the design of both the tangible product and the surrounding business structure are used with the express aim of limiting or reducing product lifetime to increase product turnover, i.e., the rate of product replacement (Assemblée Nationale, 2015), regardless of what happens with the (p)resources embedded in the product (e.g. accepting 'waste' and the destruction of added economic value). As the reduced lifetime potential resulting from planned obsolescence is not communicated by the manufacturer to the user, 'planned obsolescence' is clearly intended to serve only the interest of the manufacturer and not that of the user (nor that of the environment). The concept of planned obsolescence is compatible only with the Sell More, Sell Faster linear business model archetype and is intended to operate in a relative, linear economic, context that accepts the existence of waste.

5.4.2 Life Cycle Management and Life Cycle Engineering and Design

Life cycle engineering and *life cycle design* are an essential part of the wider concept that Westkämper, Alting and Arndt (2000) termed *"Life Cycle Management"* (Westkämper et al. (2000), p. 1). Life cycle management (LCM) is aimed at reducing the flow of energy and resources associated with a product over its entire lifecycle and belongs to the domain of Sustainable Product Design. According to Westkämper et al. (2000), *"Life Cycle Management (LCM) considers the product life cycle in a holistic way with the aim of achieving the product's maximum performance. Life Cycle Engineering (LCE), Technical Support, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and last but not least Product Data Management (PDM) are means to accomplish the protection of resources and maximize the effectiveness of usage"* (p. 507).

It is important to note that the life cycle of a product can be conceptualized in different ways, such as a series of *"physical lifecycle phases"* (Terzi et al., 2010, p. 389), i.e., design, manufacturing, distribution, use, disposal and reuse/recycling (Stark, 2015; Terzi et al., 2010), or a series of "*market-oriented"* (Stark, 2015, p. 7) life cycle phases (Stark, 2015; Terzi et al., 2010; Vernon, 1966), i.e., introduction, growth, maturity and decline (Stark, 2015; Golder & Tellis, 2004) of a product. Life cycle management and life cycle engineering and design look at the life cycle concept from the physical life cycle phase perspective.

Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are comparison-based assessment methodologies used within life cycle management to calculate the effects of different life cycle scenarios (Westkämper et al., 2000). The goal of *"Life cycle engineering and design"* (Alting & Brøbech Legarth, 1995, p. 1) is the development of *"stable product lifecycle systems that drastically reduce environmental loads, resource consumption and waste generation while increasing living standards and corporate profits"* (Fukushige, Yamamoto & Umeda, 2012, p. 1). Life cycle engineering aims to achieve this by integrating *"environmental issues and parameters into product development throughout the life cycle of a product"* (Westkämper et al., 2000, p. 513). Life cycle engineering and design are based on a four-step process that was described by Fukushige et al. (2012) as follows:

> First, designers analyse the current state of the product and its market, and determine the product concept, business strategies and environmental targets based on the results of this analysis. Second, the designers formulate a lifecycle strategy according to the product concept, business strategy and environmental targets. Third, the designers design the product and its various lifecycle processes in line with the strategy. Finally, the designers evaluate the whole lifecycle of the product to confirm the feasibility of the strategy. In short, the lifecycle strategy is planned from the early stages, and the product is designed to realize the strategy (p. 1).

As described in the current literature, life cycle design and engineering use the relative approach of *"eco-design to improve the environmental product behaviour"* (Westkämper et al., 2000, p. 514). Westkämper et al. (2000) stressed, however, that in the context of life cycle management, Design for Environment (DFE) is interpreted as an interdisciplinary approach whereby the designers and engineers take into account the effects of their design decisions on *"material processing, manufacturing, refurbishing, recycling, disposal and logistics"* (p. 514), thus ensuring that the environment as well as business-economic aspects are supported.

Within life cycle management, there are various approaches to life cycle engineering and design (Erler & Rieger, 2016; Xing, Luong & Abhary, 2005), all aimed at reducing the environmental load over a product's life time. One example from the literature, *"the Comet Circle ™"* (Tani, 1999, p. 1), is particularly noteworthy in the context of this thesis as it pertains to the systematic development of sequences of multiple reuse and/or recycling steps. The subsequent interventions for reuse and recycling within those sequences are ordered in line with the Inertia Principle and the typology presented in section 2.5 and aimed at preserving product integrity and added economic value to a maximum extent (Tani, 1999). The 'Comet Circle' concept represents a product design and management approach (developed at the Ricoh Company Ltd. (Ricoh, 2017)) that takes into account environmental as well as business-economic aspects. Although Tani (1999) asserted the 'Comet Circle' concept was specifically intended and developed to support a *"Closed Substance Cycle Society"* (Tani, 1999, p. 1) it did acknowledge the concept of waste. In the context of Tani's (1999) article, the concept of a 'Closed Substance Cycle Society' is therefore to be interpreted as 'a real-world socio-economic system that strives to minimize waste'. The 'Comet Circle' concept proposed to use *"downstream information"* (Tani, 1999, p. 2), i.e., information gained from the (needs of the) reuse and recycling processes, in the product design process to improve the suitability of products for future reuse and recycling, i.e., improve the quality of the flow of obsolete products, with the aim of making the economic benefits of the reuse and recycling processes exceed or at least equal their cost as Tani (1999) foresaw that *"to have money flow to the reverse direction* [i.e., back to the company] *will be the key to have cyclic society firmly established"* (p. 2).

All approaches within life cycle management – some aimed at a linear and others at a circular economy (e.g. Despeisse, Kishita, Nakano & Barwood, 2015; Kurilova-Palisaitiene, Lindkvist & Sundin, 2015) – have in common, however, that they are aimed at reducing the environmental load over a product's lifetime. Either next to, or with the explicit aim of, reducing the total consumption of energy over a product's lifetime, they often aim to enable manufacturers to affect or control the flow of obsolete products, by intervening before, during and/or after the start of the useful lives of their products (e.g., Erler & Rieger, 2016; Tani, 1999). Some of these approaches for example focus on closing the loop (e.g. Kurilova-Palisaitiene et al., 2015) after products have become obsolete, whereas others are more oriented towards the development of life cycles based on scenario prediction (Erler & Rieger, 2016; Inoue, Yamada, Yamada & Bracke, 2016; Fukushige et al., 2012). Until recently, most of these life cycle management approaches were based on scenarios built around 'static' products of which specifications would not change after they had entered a use cycle (Erler & Rieger, 2016). As a result, these life cycle scenarios did not include products that had *"the capability to regularly adapt to an advancing environment"* (Erler & Rieger, 2016, p. 80) but instead worked from the premise that *"products are recycled after the end of their intended usage phase and design can start again with the recycled good"* (Erler & Rieger, 2016, p. 80).

5

Recent technological developments, however, like the rise of the (availability of the) internet and the extension of its usage into tangible products, i.e., *"the internet of things"* (Erler & Rieger, 2016, p. 80), have allowed life cycle engineering and design to extend concepts known from software products into the realm of tangible products in order to prevent them from becoming obsolete, i.e., extend their useful lifetime (Erler & Rieger, 2016). Examples of these concepts, taken from the world of software products, whereby the product development and product use stages in effect run in parallel, are designing a product for future (reliability, functionality, cost and environmental performance related (Erler & Rieger, 2016; Inoue et al., 2016) updates and upgrades of which the exact nature is not known in advance and updating and upgrading a (software) product during and along its life cycle (Erler & Rieger, 2016).

5.4.3 Obsolescence Management

The aim of *obsolescence management* as presented in the current literature (e.g., Bartels et al., 2012; Rojo et al., 2009; Sandborn, 2007, 2004; Saunders, 2006) is to manage (i.e., eliminate or mitigate) the effects of one specific type of obsolescence, known as DMSMS (Bartels et al., 2012; Sandborn, 2007; Saunders, 2006). The acronym DMSMS stands for *"Diminishing Manufacturing Sources and Material Shortages"* (Saunders, 2006, p. i). According to the literature (e.g., Bartels et al., 2012; Rojo et al., 2009; Sandborn, 2007, 2004; Saunders, 2006), DMSMS obsolescence management pertains primarily to *"sustainment-dominated systems"* (Rojo et al., 2009, p. 1). Sustainment-dominated systems are *"products that have to be manufactured and supported for long periods of time"* (Sandborn, 2007, p. 1), often *"for many decades"* (Rojo et al., 2009, p. 1), and that *"have long-term sustainment costs that significantly exceed their original procurement cost"* (Rojo et al., 2009, p. 1). Many examples of this type of product can be found in the aviation and defence industries (Bartels et al., 2012; Saunders, 2006). Often the owners and/or operators of products of this type (e.g., civilian or military aircraft, complex weapon systems) *"lack control over critical parts of their supply chain"* (Sandborn, 2007, p. 1) such as electronic components (Bartels et al., 2012; Rojo et al., 2009; Sandborn, 2007, 2004; Saunders, 2006). The aim of obsolescence management is thus to prevent sustainment-dominated systems from becoming obsolete *before their time* by managing (i.e., eliminating or mitigating) the effects of the (pending) obsolescence of some of the critical components of those sustainment-dominated systems. Obsolescence management started out as a user-side, reactive set of activities that consists of *"accurately tracking and managing the availability of parts, forecasting the risk of parts becoming obsolete, and enabling the application of migration approaches when parts become obsolete"* (Sandborn, 2004, p. 1) in order to minimize the cost of resolving DMSMS related problems as they occur (Sandborn, 2004). More recently, however, some of its proponents, such as Sandborn (2004) have stressed the importance of expanding and shifting the focus of obsolescence management toward the development and implementation of *"optimum redesign strategies…for the product over the product's overall lifecycle"* (Sandford, 2004, p. 1) *"in order to minimize the cost of concurrently managing both inevitable obsolescence problems and technology insertion"* (Sandford, 2004, p. 1) from an earlier moment in time and in a more proactive manner. Obsolescence management is a predominantly reactive, user-side, endeavour. That user, in virtually all instances, is not a consumer but a business or institution that in some instances was co-designer (but not manufacturer) of the larger sustainment-dominated product or system. Many vendors and manufacturers of (electronic) components that are used in the larger sustainment-dominated systems tend to announce the pending obsolescence of one or more of their products (Bartels et al., 2012), for example a particular type of micro-processor. In many instances, however, this announcement takes place long after introduction of that particular product. Obsolescence management consists mainly of forecasting and developing appropriate responses to these types of announcements and events and is intended protect the user's investment in complex and expensive, sustainment-dominated, products and systems by keeping these products and systems operational for as long as possible and/or needed.

5.4.4 Product Lifecycle Management

Product lifecycle management (PLM), *"has been widely adopted and defined by different communities (vendors-based, academic-oriented, end-users, etc.)"* (Terzi et al., 2010, p. 365). The concept of PLM is of relatively recent origin as it *"emerged at the beginning of the twenty-first century and has been evolving since then"* (Stark, 2015, p. vi). The concept of PLM displays some similarities to the concept of lifecycle management introduced above, and more recently the circular economy concept has started to appear in (grey) literature on PLM (e.g. Tata consultancy services' (Tata, 2016) white paper "Redefining Product Lifecycle Management in a Circular Economy"). However, the concepts of lifecycle management and PLM are not the same. Where the concept of life cycle management has its roots in sustainability thinking (Westkämper et al., 2000) and puts an emphasis on *"drastically reducing environmental loads, resource consumption and waste generation"* (Fukushige et al., 2012, p. 1), the drivers for the development of PLM have been primarily business-economic (Stark, 2015). Although environmental concerns are part of PLM, they tend not extend beyond compliance to environmental regulations and health and safety concerns (Stark, 2015). The concept of PLM was developed to help companies respond to, and remain competitive in the face of, the many changes that took place at the end of the twentieth and beginning of the twenty-first century, for example the rapid succession of new technological developments (e.g., electronics, software, bio-tech, nano-tech) affecting the nature of products, the shortening of product development times, environmental issues (e.g. global warming) and geopolitical issues (e.g. globalisation) Stark (2015). The interpretations of PLM by various actors within the different communities mentioned above differ slightly (Terzi et al., 2010) in line with their respective interpretations of the product lifecycle concept (Stark, 2015; Terzi et al., 2010) (see 'lifecycle management and lifecycle engineering and design' above). Grieves (2005) defined PLM from the 'physical lifecycle phases' perspective as *"an integrated, information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life, from its design through manufacture, deployment and maintenance—culminating in the product's removal from service and final disposal"* (p. 39). From the same 'physical lifecycle phases' perspective, Stark (2015) defined PLM as *"the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of"* (p. 1). With this definition, Stark (2015) expanded on the "*cradle-to-grave"* Stark (2015) - or *"sunrise to sunset"* (Stark, 2015, p. 8)- based definition adopted by Grieves (2005) (Terzi et al., 2010) mentioned above, by extending the definition of PLM to also include the earliest, ideation or inception, part of the product lifecycle (i.e., from *"dawn to dusk"* (Stark, 2015, p. 8)

5

instead of 'cradle to grave'). Stark's (2005) definition also aimed to reflected that *"PLM is not a mere ICT problem"* (Terzi et al., 2010, p. 366), thereby extending the scope of PLM beyond the narrower ICT (information and communication technology) perspective on PLM as taken for example by Saaksvuori & Immonen (2005). In addition to providing a new definition, Stark (2005) furthermore stressed that *"at the highest level, the objective of PLM is to increase product revenues, reduce product-related cost, maximise the value of the product portfolio, and maximise the value of current and future products for both customers and shareholders"* (Stark, 2005, p. 1) According to Githens (2007), the concept of PLM is described in most of the literature (e.g. Stark, 2015; Terzi et al., 2010; Grieves, 2005; Saaksvuori & Immonen, 2005) as *"a technology and a process"* (p. 279) for increasing the efficiency and reducing the cost of developing, manufacturing and servicing and disposing of products over the 'physical lifecycle phases'. With the additional statement mentioned above, however, Stark (2015) brings the concept of PLM as defined from a 'physical lifecycle phases' perspective closer to the marketing-oriented (Githens, 2007) definition of PLM as provided by the Product Development and Management Association (PDMA, 2017). The latter definition puts less emphasis on the potential of PLM for improving operational efficiency and more on the potential of PLM for effectively managing the creation and capture of value over the entire lifecycle, i.e., throughout the various 'market lifecycle stages', of a product. The Product Development and Management Association glossary defined PLM from a market-oriented lifecycle perspective as *"changing the features and benefits of the product, elements of the marketing mix, and manufacturing operations over time to maximize the profits obtainable from the product over its lifecycle"* (PDMA, 2017).

Within the larger domain of PLM, five main areas of expertise can be discerned: *"business processes, product data, information systems, organisational change management (OCM) and project management"* (Stark, 2015. p. vi). The single defining characteristic of PLM, however, despite the slight differences in definitions, is that it is holistic (Stark, 2015; Terzi et al., 2010). It is aimed at aligning and coordinating the various activities of managing a company's products by defining and documenting them, *"across the product lifecycle"* (Stark, 2015, p. 3) in *"cross-functional business processes"* (Stark, 2015, p. 3) and a *"cross-functional product data management (PDM) system"* (Stark, 2015, p. 3) in order to remove, and prevent future (re-)occurrence, of the potential problems associated with the fragmented, departmental approach that until the advent of the concept of PLM - around 2001 - was the paradigm for managing a company's products (Stark, 2015; Terzi et al., 2010; Ibrahim & Paulson, 2008; Grieves, 2005), PLM thus is a *"high level business activity"* (Stark, 2015, p. 8). that aims to harmonize *"lower-level product-related activities of a company"* (Stark, 2015, p. 3) in order to achieve two main objectives: First, *"to improve the product-related performance of a company"* (Stark, 2015, p. 1) either through reducing cost or increasing revenues or both, and secondly, *"to put in place, or to improve, the capability to manage products across their lifecycles"* (Stark, 2015, p. 1) An example of some of these lower-level product-related activities is given in table 5.4.1 below, reproduced from Stark (2015).

The lower-level activities from table 5.4.1 in turn consist of sets of other activities. To illustrate the complexity and scope of PLM, the many sub-activities for just one of the lower-level activities from the above table, i.e., "managing products across the lifecycle", are presented as an example here. According to Stark (2015), "managing products across the lifecycle"

Managing a well-structured and valuable Product Portfolio
Maximising the financial return from the Product Portfolio
Managing products across the lifecycle
Managing product innovation, development, support and disposal projects effectively
Providing control and visibility over products throughout the lifecycle
Managing feedback about products from customers, products, field engineers and the market
Effectively managing product requirements
Enabling collaborative work with design and supply chain partners, and with customers
Managing product-related processes so that they are coherent, joined-up, effective and lean
Capturing, securely managing, and maintaining the integrity of product definition information
Making product definition information available when it's needed, when it's needed
Knowing the exact characteristics, both technical and financial, of a product throughout its lifecycle

Table 5.4.1: Some of the lower-level product-related activities within the scope of PLM, reproduced from Stark, 2015, p. 8.

> includes activities such as organisation and co-ordination of product-related resources, decision-taking, setting objectives and control of results. A product must be managed in all phases of the lifecycle to make sure that everything works well, and that the product makes good money for the company. The product needs to be managed when it's an idea. Product ideas need to be managed to make sure, for example, that they aren't lost or misunderstood. The product needs to be managed when it's being defined. For example, a product development project has to be managed to be sure the product meets customer requirements. The product needs to be managed when it's being realised. For example, it's important that the correct version of the definition is used during production. The product needs to be managed when it's in use. For example, the product must be correctly maintained, taking account of its serial number, production date, previous upgrades, changes in the market and technical evolution. The product needs to be managed at disposal time. Care has to be taken to make sure that poisonous components and toxic waste from the product don't get anywhere near sources of drinking water (p. 7).

5

Because PLM has such a wide scope and covers a vast array of business activities and company types (Stark, 2015; Terzi et al., 2010), the concept embraces and brings together different - but related - interpretations of the lifecycle concept (e.g., user, manufacturer, marketing and environmental) as mentioned above. In addition, PLM also utilizes many different lifecycle models (Terzi et al., 2010), for, as Terzi et al. (2010) explained, lifecycle models are highly product type dependent:

> a lifecycle model depends strongly on the product type, which affects enterprise business processes. In fact, the product could be a complex long-life manufacturing object (e.g. a car, a plane or a turbine), a complex short-life manufacturing object (e.g. a PC, a CD player or a camera), a pharmaceutical specialty (e.g. a vaccine or an antibiotic), a building (a house or a flat), a fashion garment, etc. (p. 366).

5.4.5 Planned for Obsolescence

The concept of *planned for obsolescence* was introduced by Burns (2010). Burns (2010) asserted that the onset of obsolescence ultimately is inevitable and is highly complex in the sense that the reasons for, and timing of, the onset of obsolescence can vary widely between products of different categories. With the concept of 'planned for obsolescence', Burns (2010) proposed to reduce the environmental impact of tangible products by accepting the inevitability of obsolescence (in one of its many guises) and to take into account already during the design process of the tangible product the multitude of often product type dependent factors affecting the timing of the onset of obsolescence, such as the maturity of the product and its market, level of servitisation (Beuren et al., 2013; Vandermerwe & Rada, 1988) and the speed of technological developments in certain product categories. The option of multiple use cycles for tangible products, however, is not elaborated upon by Burns (2010). In line with the literature (e.g. (Bakker, Wang, et al., 2014; Van Nes & Cramer, 2005; Charter & Tischner, 2001; Tischner et al., 2000)., the concept of 'planned for obsolescence' furthermore acknowledges that, in some instances, a longer product lifetime does not lead to a reduction in environmental impact and that there therefore is such a thing as *"appropriate longevity"* (Burns, 2010, p. 59), i.e., a product lifetime that befits the particular conditions surrounding a product. As evidenced by Burns' (2010) use of the terms *"reduced environmental impacts"* (p. 44) and *"minimization of waste"* (p. 44.), the concept of 'planned for obsolescence', like the concept of 'planned obsolescence', is intended to operate in a relative, linear economic, context that accepts the existence of waste.

5.4.6 Results from the Literature Review

The various approaches for affecting the flow of obsolete products discussed in the previous sub-sections yield a number of valuable insights.

Economic or Environmental: Drivers for Affecting and Controlling Obsolescence

The review of the literature makes clear that industrial design and/or business practices to affect or control the (quality and/or quality of the) flow of obsolete products already have a long history (Burns, 2010; Slade, 2007; Adamson, 2003; London, 1932).

Although the literature agrees that the onset of obsolescence is ultimately inevitable, the primary goals and drivers for affecting the flow of obsolete products can be seen to change over time. The review shows that historically most of the existing approaches for affecting the flow of obsolete products have been driven either by economic or by environmental objectives. Approaches driven purely by business-economic objectives (e.g. planned obsolescence) generally aim to hasten the onset of obsolescence, often regardless of environmental consequences. Approaches driven by environmental objectives tend to strive to postpone or mitigate the effects of the onset of obsolescence.

Two approaches, however, stand out as they deviate from this general pattern of wanting to postpone the onset of obsolescence for environmental reasons and striving to hasten the onset of obsolescence for business-economic reasons.

The first of these is obsolescence management that, although driven by business-economic motives, is aimed at postponing the onset (and mitigating the effects) of obsolescence of a tangible product or system in order to protect a business' or institution's investment in that particular product or system.

The second is PLM that, as can be seem most clearly from the definition by the PDMA (2017), in some instances also aims to postpone obsolescence for business-economic reasons. The interventions for postponing obsolescence that result from this striving, however, generally do not reduce, but often rather increase, the environmental load. They are not aimed at affecting obsolescence as it can occur within a product's physical life cycle, i.e., at the individual, tangible product level. Rather, they are targeted at affecting obsolescence as it can occur within the marketing life cycle, i.e., at the more abstract level of a particular model of tangible product. Altering the *"elements of the marketing mix"* (PDMA, 2017) for a particular product, especially for a product that is past its marketing life cycle prime (e.g., in the late maturity or decline product life cycle stage, see Appendix E: The Product Life Cycle and Related Concepts), can enable a company to extend the period over which outdated products can be traded, thus offering a company a longer period to profit from its investments in the development of and manufacturing equipment for that particular product model.

Over time, however, the goals and drivers of different approaches have slowly begun to converge. Approaches driven by environmental drivers (e.g., life cycle management and life cycle engineering and design) initially emerged to counter the (environmentally disastrous consequences of the) success of approaches driven purely by business-economic drivers (e.g., planned obsolescence). More recent instances of both types of approaches for affecting the flow of obsolete products, however, like Tati's (1999) 'Comet Circle™' concept, Burn's (2010) 'planned for obsolescence', and developments in product life cycle management as presented in Tata's (2016) publication 'Redefining Product Lifecycle Management in a Circular Economy', are aimed at the alignment of business-economic and environmental interests and intended to serve both.

A Need and Approaches for Affecting but no Need or Approaches for Controlling the Flow of Obsolete Products

The need to *affect* the flow of obsolete products is clearly articulated in the literature. At present, the literature contains several approaches for affecting the flow of obsolete products and/or mitigating the effects of its unpredictability. Manufacturers can, for example, decide to introduce a newer, more attractive and feature rich, product and/or end support, e.g. halt the manufacturing and supply of spare parts, for an older product it is intended to replace. Although approaches like these can affect when users discard certain products, they cannot do so with certainty nor do they allow the manufacturer to regain control over the obsolete products.

The review makes clear that the literature does not contain an approach that allows manufacturers to actually *control* the flow of obsolete products to a maximum extent, e.g., to control what happens with their older (and/or obsolete) products that remain out in the world and are owned by their respective users.

Because the current approaches, such as life cycle management, life cycle engineering and design, planned for obsolescence, are rooted in linear economic thinking that supports a relative approach to sustainability, there is also no pressing need for manufacturers to control the quality and/or quantity of the flow of obsolete products to a maximum extent. Even Tati's (1999) closed substance cycle, 'Comet Circle™' concept accepts the concept of waste. From a relative perspective on sustainability, it is acceptable and considered sufficient that these existing approaches provide manufacturers with ways for *reducing* (instead of *minimizing*), the environmental load by *affecting* (instead of *controlling*), the flow of obsolete products. Some of the existing approaches for affecting the flow of obsolete products, such as planned obsolescence and the PLM example of affecting obsolescence in the marketing lifecycle instead of the physical lifecycle, are not even intended for reducing the environmental load at all. In many instances, these approaches were developed only to increase business revenues. As approaches like these often rather contribute to increasing instead of reducing the environmental load, their inherent lack of control could even be considered a benefit from an environmental point of view.

Benefitting the Manufacturer but not the User
Most of the current approaches for affecting the flow of obsolete products from the literature have clear and direct benefits to manufacturers only. For many of the current approaches for affecting the flow of obsolete products in the current literature it is - at best - unclear how they benefit the user. Where in the instance of life cycle management for example, the user can be said to benefit in an indirect way, from a cleaner and less depleted environment, the benefits for the user of a business centred approach like planned obsolescence are virtually non-existent.

Lack of Communication of Product Lifetime
None of the approaches for affecting the flow of obsolete products from the literature pro-actively communicate the expected duration of use cycles or product lifetimes. As such, many of the existing approaches make it - in addition to not benefitting the user - difficult for users to limit their losses as without this information it is virtually impossible for the user to accurately weigh the cost of a product against its expected benefits.

A Range of Options but no Guidance
Corroborating what was said in previous chapters of the thesis, the review of the literature shows that the spectrum of means that can and have been used for affecting obsolescence over a product's lifecycle, extends beyond changes in *"attributes formed through design and manufacture"* (Cooper, 2010, p. 8), i.e., the design of the tangible product. The spectrum of means also includes changes to the various *"elements of the marketing mix"* (PDMA, 2017), e.g. the business model type that the product is embedded in. These elements of the marketing mix could for example be employed to adjust the overall value proposition to compensate for the tangible product's worsening position in the marketing lifecycle.

The literature (e.g., Burns, 2010; Terzi et al., 2010) furthermore makes clear that managing a product's lifecycle, including affecting the onset and effects of its obsolescence, is not a matter of 'one-size-fits-all' but rather is highly product type and context dependent.

The literature, however, does not provide examples of how companies go about creating, delivering and capturing value from durable consumer goods with a potential for a long or extended product lifetime and the challenges they face in doing so.

Already important in closed-loop supply chains in a linear economic context, the ability to control the quality and quantity and minimize the randomness of the flow of obsolete products is clearly essential in a circular economy. Maximizing business model circularity in a circular economy requires a level of control over the flow of obsolete products that will preferably enable a manufacturer to (pre)determine when, and in what way, tangible products will become obsolete and when, and in what way, they will be recovered. None of the approaches for affecting the flow of obsolete products present in the current literature, however, offer that level of control (see table 5.5.1). As the current literature furthermore provides little insight (other than process and geometry related issues like ease of (dis) assembly and part or material separation (Atasu et al., 2008, Navin-Chandra, 1994)) into how industrial designers can help companies gain control over the unpredictable variations in the age, condition and volume of the flow of returns (see sub section 5.3.2) we will in the next section present the results from research (i.e., interviews and company visits) that we have conducted at companies that currently create and capture value from preserving product integrity to gather empirical data to help fill this gap in the literature. The purpose of the interviews and visits is to increase our understanding of the workings of - and challenges for -companies in different industries that currently manufacture and market products with a long or extended lifetime in order to find out in what ways industrial designers in a circular economy could contribute to removing, or at least mitigating the effects of, the two barriers to maximizing business model circularity.

In the remainder of chapter 5 we will then, based on the findings from the literature and the results from the company interviews and visits, present (the development of) a new design and management approach to control the flow of obsolete products to a maximum extent that is intended expressly for use in a circular economy.

5.5 PRESERVING PRODUCT INTEGRITY IN PRACTICE: COMPANY INTERVIEWS AND VISITS

This section presents the results from five company interviews and two three-day company visits. Most of the information presented below was conveyed in conversations with representatives from the respective firms during the interviews or the company visits and as such – with the exception of literal quotes – is not referenced separately. However, in multiple instances, factual information from secondary sources is added to provide additional background with regard to the respective companies. These secondary sources, however, are explicitly referenced for clarity.

5.5.1 Miele
The interview with Mark Huijsmans, Marketing Director Miele Nederland, and Ad Verheijen, Product Manager, took place at the Dutch Miele headquarters in Vianen, the Netherlands, on September 10th, 2012.

Miele is a privately owned, German, manufacturer of premium professional and domestic appliances, e.g. washing machines, dryers, ovens, micro-waves, refrigerators and vacuum cleaners. Founded in 1899 by Carl Miele and Reinhard Zinkann with their quality motto *"Forever better"* (Miele, 2013), it now has over 18.000 employees (Miele, 2016; 2013). Over the years, Miele's turnover has displayed a remarkably steady growth, showing only one minor dip of 1,3% in 2009 during the years of financial crisis 2007-2008-2009 that was followed by record sales already in 2011 (NRC, 2011). Through its own sales & service subsidiaries in 47 countries, and a network of importers and distributors in another 50 countries (Miele, 2013), Miele generated a turnover of 3,71 billion Euro in the 2015/2016 business year (Miele, 2016). As a privately-owned company, Miele never publishes information regarding its profits

5

(NRC, 2011). Miele predominantly trade the ownership right to their domestic appliances, although there is the occasional Miele Laundrette (see also Miele, 2017b) that operates by trading rights of use. Some of the latest series of Miele washing machines have dosing technology that uses proprietary consumables in the form of detergent containers (see also Miele, 2017c), in effect representing a first move towards a hybrid business model type (i.e., a long-life durable consumer product combined with short-lived, dedicated consumables) (see sub-section 4.7.1).

"Durability and reliability" (Miele, 2015, p. 7) of the Miele products is of the highest importance to Miele, both from a company and a stakeholder perspective. Longevity is at the heart of the Miele brand and can be seen represented in all aspects of the business model: *"A strong characteristic of the Miele proposition is that it is not just the appliance…everything is designed for longevity, materials are procured for longevity, suppliers are selected for longevity…it all has to fit together"* (Huijsmans, Miele interview, 2012). Miele's domestic washing machines for example are designed for longevity and the designs are subjected to tests to ensure they will last for at least 20 years of 'normal family use'. Miele operate their own fleet of bright red Miele branded service vans and train their own service personnel before authorizing them to do maintenance and repairs). Miele manage their operational structure in such a way that design engineers gradually transfer from the product development to the service department over the course of their careers, in line with the model lifecycles of the equipment they designed, preserving older product expertise whilst at the same time securing continuity of employment for their employees. Only once in their 118 years of existence, in 2005, have Miele been in a situation where they had to lay-off 1077 employees (NRC, 2011).

Figure 5.5.1: Miele 'wedding dress' advertisement Image source: https://files2.coloribus.com/files/adsarchive/part_492/4920705/file/washing-machine-wedding-dress-small-50035.jpg

Relations with suppliers are maintained over long periods of time as well, making it possible to employ supplier expertise in product development and securing the availability of spare parts for older units. Miele actively communicate their commitment to product longevity not only to the market (see advertisement in figure 5.5.1) but also within the company, where they for example anchor their business philosophy by means of a – limited edition – longevity *brand book*.

Continuously aiming for product durability and reliability does not come without challenges. Combining high grade and high-quality products with operating at, and maintaining, a price point that is perceived by consumers as competitive is not always easy and requires special attention: *"We do not talk about the price of our product, rather, we talk about its value"* (Verheijen, Miele interview, 2012). This is especially so with the increasing share of internet sales that offer limited opportunities (e.g., no trained salesperson and no appliances that can be inspected for a real live comparison) to explain and support the benefits of a washing machine or vacuum cleaner with a potential for an extended lifetime but a significantly higher price tag then, often shorter lived, competing offers. As part of meeting this challenge, Miele have changed their marketing communication from stating features (e.g. number of revolutions and capacity in kilogrammes) to presenting *key benefits* in more consumer-oriented language: *"We care for what you wear"* (Huijsmans, Miele interview, 2012).

Miele's commitment to durability and reliability also makes it more difficult to adopt and/or match features that are presented as innovations by competitors. Power cables with a flat, rectangular cross section on vacuum cleaners for example offer more reach and take less space when rolled up. Despite these advantages as promoted by competitors, Miele have chosen not to adopt flat power cables as the directionality of their cross section makes them less easy to spool up and more prone to twisting and bending, limiting their lifespan in comparison with the round cross power cables that Miele continues to use:

> We bring a solution *[to a particular problem]* to the market when we have a solution to the problem *[that meets our standard]*, and not before. You may call this stubborn, but it is part of our philosophy. We do not want to put tens of thousands of appliances in the market that will lead to one complaint after the other after two or three years (Verheijen, Miele interview, 2012).

A brand name that represents durability and reliability in itself can be the cause of unwanted side-effects. Miele have found for example that the number of service calls and/or complaints concerning Miele manufactured appliances is higher when the appliances are sold under the MIele brand name then when virtually identical (e.g., minor, branding related cosmetic differences only) appliances are sold under a different brand name, naming as one probable cause a higher level of customer expectation as a result of the Miele brand name. Another side effect of the perceived value and popularity of the Miele brand name mentioned was that it apparently pays to repair and/or rebuild obsolete Miele washing machines and sell them on the second-hand market. As Miele do not take back and rebuild obsolete machines themselves but make use of the existing and general disposal channels for obsolete domestic appliances, the repairing and/or rebuilding is often done by hobbyists and other third parties over which Miele has no control. In case of defects and/or accidents with these potentially unsafe machines, the Miele brand name is harmed by association as these uncertified machines still carry the Miele logo. However, *"Miele appliances, in particular those for washing, drying and vacuum cleaning, are 100% recyclable…all our plastics are recyclable and coded…where with most competitors the counter weight* [of a washing machine] *is made out of concrete, we make it out of cast-iron"* (Verheijen, Miele interview, 2012).

5.5.2 Eastpak

The interview with Toon Kympers, Vice President Product & Merchandising Eastpak, took place at the Eastpak European headquarters, Hingene, Belgium on July 18th, 2013.

The Eastpak bags and luggage brand was born in 1976, when Eastern Canvas Products Inc., a North American company that had been manufacturing duffels and pack for the U.S. Army since 1952, started to make backpack for college campus use (Eastpak, 2017). In 1984, the Eastpak brand became the first bags and luggage brand to offer a lifetime warranty (now officially 30-year warranty for legal reasons) for their products (Eastpak, 2017). The Eastpak brand is currently owned and exploited by the VF (Vanity Fair) Corporation (VFC, 2017). Working with over 60.000 associates worldwide, the VF corporation reported global revenues of 12 billion USD over 2016 (VFC, 2016). Eastpak trade the rights of ownership to their products. Its products can be bought from department and specialty stores and online in Europe and Asia (VFC, 2016). Because of their reputation of durability, Eastpak products are sold at a premium price point. Product longevity is central to the identity of the Eastpak brand:

> The Eastern Canvas company made bags for the US army that had to meet army quality standards. The specifications for resistance to wear and tear, longevity, tensile strength were very high...for a soldier, having his gear at hand is a matter of life and death. We use that same philosophy with regard to quality standards to this day. We have the A1 and C1 quality standards that are still in line with what the Pentagon asked in 1952 (Kympers, Eastpak interview, 2013).

The longevity of their products is therefore explicitly communicated to the public as can for example be witnessed from their tag line *"built to resist"* (Kympers, Eastpak interview, 2013) and their skeleton ad shown in figure 5.5.2.

Figure 5.5.2: Eastpak 'skeleton' ad. Image source: www.eastpak.com/oc-en/about_eastpak/.

Although Eastpak's quality standards do increase the market price of their products, they also result in products with very long lifetimes. Eastpak backs their products with a lifelong warranty, that for legal reasons, they had to reduce to 30 years for Europe. Like Miele in the previous interview, Eastpak managed to weather the economic crisis and found that during times of economic crisis, consumers are willing to pay a bit more if that means that they can be certain that the product is of a good quality.

At Eastpak, product design plays an important role in manufacturing and marketing products with a longer lifetime. Apart from the materials that are used, the geometry of the construction is essential. Eastpak's archetypical *"Padded Pak'r"* (Kympers, Eastpak interview, 2013) backpack (see chapter 3, figure 3.7.6) for example was designed in the 1970's by an engineer trained in design for manufacturing. The main body of the backpack is made from a single piece of cloth that is put into its final shape with a single continuously stitched seam during manufacture, thus reducing the risk of seam failure during use. The only addition is a small pouch on the front. As such, this backpack embodies two rules of thumb for designing long-life products at Eastpak. *"Design for manufacture"* (Kympers, Eastpak interview, 2013) and *"Strip everything that is banal and not necessary from a product. What you see is what you use"* (Kympers, Eastpak interview, 2013). At any time, roughly two thirds of Eastpak's product portfolio consists of products that are not really sensitive to fashion and are carried over, i.e., are *"never out of stock"* (Kympers, Eastpak interview, 2013), for 24 to 72 months. Even for the one-third of their product portfolio that is sensitive to fashion, Eastpak aims to design the products in such a way that they can be used for multiple seasons, for example by choosing colours that are fashionable but at the same time are not extremely short lived *"hype-colours"* (Kympers, Eastpak interview, 2013). According to Kympers, *"industrial designers must receive a very precise briefing* [that provides guidance] *for 80%* [of a project] *in order to be able to work highly effective and efficient...They also always get 20% freedom to do blue-sky thinking, think outside the trodden paths...The 80% accuracy of the briefing must indeed be in line with the long-term vision of the company"* (Kympers, Eastpak interview, 2013) as a company like Eastpak cannot have *"zigzag-management"* (Kympers, Eastpak interview, 2013).

To anchor and convey their commitment to product longevity inside the company and explain to their designers how this affects and is affected by design, Eastpak (like Miele in the previous interview) has produced a *brand book* that describes *"in an Eastpak manner...a methodology...a script for product* [design]*, marketing and sales"* (Kympers, Eastpak interview, 2013). Besides text, this Eastpak Playbook, or *"list of values for product development"* as Kympers (Eastpak interview, 2013) also referred to it, contains lots of imagery of both people (e.g. lifestyles) and different types of luggage to help convey the Eastpak look & feel and thus provides guidance to the Eastpak designers with regard to functionality (e.g., size, number and placement of handles, straps, compartments and pockets) and construction (e.g., materials and types of connections, fasteners and closures) as well as style (e.g., cut, colour, patterns and materials).

As Eastpak is part of a the larger, globally operating, VF corporation, many of the back-office services are consolidated. Eastpak brand management, however, is a very small and separate team. Within this team, business functions are integrated. There are no separate product designers, product developers and product managers, but only multidisciplinary *"product merchandisers"* (Kympers, Eastpak interview, 2013) who are involved from A to Z. They perform market and portfolio analyses, develop of the merchandizing plans, develop the design briefs, do the actual design, do pricing and costing and present at sales meetings. This team of multidisciplinary product merchandisers travels a lot. As Eastpak does not have their own factories, the last phase of the development is done at the location of one of the VF corporation's limited number of strictly selected vendors, ensuring that the final design fits the vendor's manufacturing capabilities.

From their research, Eastpak has learned that when owners of an Eastpak backpack finish college or university, their backpacks are not discarded. When, as a result of their changing needs (i.e., from school to work situation) Eastpak backpack owners switch to a different type of (Eastpak) bag, the old backpack is often handed down to a sibling or is used for leisure instead of school activities from then on.

The emotional connection between the owners and their Eastpak backpacks is often quite strong. In some instances, there have been reports of broken backpacks sent in for repair under warranty that were accompanied by a letter with a request (for reasons of emotional attachment) to return the backpack to its owner instead of exchanging it for a new one under warranty in case it could no longer be repaired.

5

Combining product longevity with a fashion item is not Eastpak's only challenge. Bringing together their commitment to product longevity with their commitment to sustainability is another. The high level of durability, i.e., resistance to wear and tear during use, puts high demands on the textiles and other materials used. Finding (and applying) materials that combine sustainable properties (e.g., recyclability or compostability) with a high resistance to wear and tear over years of intensive, daily use is not an easy feat and at the time of the interview was not yet deemed possible by Eastpak.

5.5.3 BMA Ergonomics

The interview with Harm Leskens, Head of Product Development, took place at the Dutch BMA Ergonomics headquarters, Zwolle, the Netherlands, on July 18th, 2012.

BMA Ergonomics is an ergonomics consulting firm and manufacturer of ergonomic office chairs located in the Netherlands. Founded in 1988 as an ergonomics consulting firm, BMA Ergonomics soon after started to design, manufacture and market their own office chairs as they found that existing products in the market that meet their (ergonomic) requirements were sparse. Since July 2015, BMA Ergonomics is part of SB Seating (Scandinavian Business Seating). Selling its products in over 40 countries through fully owned subsidiaries and independent dealers, SB Seating is *"one of the leading manufacturers of office chairs in Northern and Western Europe"* (BMA, 2017) with around 460 employees and factories in Sweden and Norway (BMA, 2017). According to its 2016 annual report, SB Seating is committed to sustainability as witnessed by one of its products, the HÅG Capisco, being awarded the prize for the *"Best Recycled Plastic Product in Europe"* by the European Association of Plastic Recycling and Recovery Organisations (EPRO) (SB Seating, 2015). Of their 2015 turnover of 1180 million NOK (129,1 million Euro), 8% was generated by BMA Ergonomics (SB Seating, 2015). At the time of the interview, BMA Ergonomics primarily traded the rights of ownership to its office chairs, although they were also conducting experiments with trading the rights of use.

Improved work posture and ergonomics, and not fashion or style, are at the centre of BMA Ergonomics' value proposition:

> We don't really want to be a manufacturer, but rather an ergonomics consulting firm. On the basis of our knowledge of the human body and of working in office environments we try to develop products. We think that we master this knowledge about the human body in particular, at the same time this means that we develop a product that for the time being will not be subject to change, because the human body is more or less as it is. The only things that change in that respect are the way we work and similar changes in environment…This is our unique selling point…As such, we are less subjected to changes in design and other things around us than others…This allows us to keep our office chairs 'alive' for so long (Leskens, BMA Ergonomics interview, 2012).

As a direct consequence, the BMA Ergonomics office chairs have been subjected to only a limited number of stylistic model changes over time (see figure 5.5.3). According to Leskens, quick model changes would have served no purpose other than causing existing customers to doubt the design and engineering underlying their previous models.

Figure 5.5.3: BMA Ergonomics office chair time-line. Image source: https://www.bma-ergonomics.com/wp-content/uploads/2015/05/Tijdslijn-88-151.png

At the heart of the BMA Ergonomics office chairs is a proprietary movement mechanism that is used in virtually all of their office chairs. This mechanism was developed from the onset to incorporate all of BMA Ergonomic's requirements. As a result, this proprietary movement mechanism has also remained largely unchanged over time.

At the time of the interview, BMA Ergonomics' office chairs carried no electronics and thus consumed no energy during use. An internal LCA analysis showed that transport contributes little to the environmental load over the lifetime of the office chairs as transport distances are short and many office chairs can be fitted in a single lorry. The vast majority of the environmental load (95%) is therefore generated in the manufacturing stage.

Because of the combination of high build quality, proprietary movement mechanism and the limited number of cosmetic changes, BMA Ergonomics' office chairs in theory are ideally suited for product lifetime extension. In practice, however, not all office chairs return to BMA Ergonomics after the initial period of use as, at the time of the interview, most of the chairs were still traded by selling the rights of ownership and only some of the office chairs were leased out to customers. To ensure that the office chairs are returned to BMA Ergonomics after use, arrangements for take back with regard to the timing and the financial conditions (for example in the form of a fixed price per office chair at take back or a discount on the purchase price of new BMA Ergonomics office chairs) are often made in advance. Those office chairs that do return BMA Ergonomics after the initial period of use, however, often require only a minor cosmetic 'brush-up' and a quality check (function and safety) before they can be redeployed in the second-hand market. The initial product use cycle of a BMA Ergonomics office chair is 7-10 years, but under normal use conditions the initial product use cycle of these office chairs could easily be as long as 20 years. BMA Ergonomics learned from experience that the majority of failures, if they occur at all, occur in the first few months of use after primary manufacture. In general, office chairs that do not fail in these first few months, or chairs that failed but have been repaired, will continue to function flawlessly for many years to come. Because these office chairs require so little work before they are ready for their second life, the refurbishing process generates profits that are comparable to, and in many instances even exceed, profits made on newly manufactured office chairs. To limit potential cannibalizing effects, the channels (e.g., showrooms and outlets) BMA Ergonomics uses for selling *second-life* office chairs are different from those used for newly manufactured office chairs.

5.5.4 Océ

The interview with Niels Beerens, Manager Asset Recovery & Remanufacturing and Nord van Kessel, Team Leader Asset Recovery, took place at the Dutch Océ headquarters, Venlo, the Netherlands, on October 23rd, 2013.

The history of Océ goes back as far 1857 when Dutch chemist Lodewijk van der Grinten started a pharmacy that around 1877 grew into a family business that manufactured colorants for colouring butter and margarine (Canon, 2017a; Océ, 2017b; Océ, 2017c). Product lifetime extension is an integral part of Océ's history, for it was after finding a way to improve the longevity of the materials used for making blue prints that the company in 1920 started operating in the market for printing and copying (Canon, 2017a). The company got its current name from a breakthrough process for blue print reproduction it invented and introduced to the market in 1930 under the name 'Océ' (Océ, 2017c). In 2009, Océ was acquired by Canon Inc. of Japan and officially became a Canon company (Océ, 2017b, Canon 2017b). The revenues of Canon Inc. amounted to 29,3 billion USD over 2016 (Canon, 2016). Océ trade the rights of ownership to the copiers and printers they design and manufacture, either directly to an end user or to a leasing company. Océ's main source of revenue, however, is the provision of (maintenance) service and dedicated consumables (e.g., toner cartridges and paper) for their copiers and printers. As the printing and copying hardware is a necessary part of Océ's business, but in itself only a secondary source of revenue, recovery of assets and remanufacturing of machines is important to the profitability of Océ. Giving machines and/or parts a second life not only reduces manufacturing cost. It also allows Océ to bring some of their high-grade products to the market at a lower price point, thus increasing the user base for their main source of revenue. Océ's AR/REMAN (Asset Recovery and REMANufacturing) department is responsible for ensuring these processes happen as efficiently and effectively as possible. Finding the right balance between equipment longevity, component longevity, component cost and technological progress is a complex issue. Although cheaper (but often shorter lived) components and permanent methods for joining parts (e.g., welding instead of bolting) bring down the cost price of a unit, they at the same time tend to reduce its longevity and flexibility for accommodating newer technology and use in other configurations. As there are no absolute guidelines for these type of decisions, aligning the (internal) design and engineering department with the AR/REMAN department is not always easy and requires fostering mutual understanding and carefully managing the communication between the different departments.

Once the ownership rights to their products have been sold, it can be difficult for Océ to get the copiers and printers back after a certain period of use. On some occasions, *take-back agreements* (i.e., contracts that for example describe a fixed buy back price and use term) are made at the moment of the sales transaction. In other instances, it turns out that the machines and/or components are deemed so valuable in the open market that they are sold to the highest bidder, that not necessarily always is Océ themselves. Another challenge for Océ is that certain countries (for example China), notwithstanding the high perceived use value of used Océ machines and parts in some markets and parts of the world, do not allow the import of remanufactured products, even though Océ's remanufactured copiers and printers in most instances are virtually indistinguishable from new units manufactured completely out of previously unused parts.

5.5.5 Arrow Value Recovery

The interview with Joep van Loon, Managing Director, took place at the Arrow Value Recovery, Culemborg, the Netherlands, on December 12th, 2012.

Arrow Value Recovery started their business of recovering and recycling computers in the Dutch town of Culemborg in 1995 as Flection. Their name changed to Arrow Value Recovery as they were acquired in 2011 by the Arrow Electronics Inc., a North American *"global provider of products, services and solutions to industrial and commercial users of electronic components and enterprise computing solutions"* (Arrow, 2016, p.3) with overall revenues of over 23,3 billion USD over 2015.

Arrow Value Recovery is a worldwide provider of IT asset disposition (ITAD) (Arrow, 2017). ITAD businesses aim to dispose of obsolete IT equipment in a safe and environmentally responsible manner (TechTarget, 2017). Over the years, the range of IT equipment has increased and expanded from desktops, notebooks and servers to mobility products like tablet computers and mobile phones). According to Van Loon (Arrow Value Recovery interview, 2012) the awareness of the security risks (i.e., sensitive data), however, especially for the mobility devices, is (at the time of the interview) not yet as widespread as it should be.

Arrow Value Recovery has three main revenue streams: service fees for handling and processing obsolete IT equipment, (a share in the) proceeds from selling refurbished IT equipment and proceeds from selling recovered metals to material recycling companies such as Umicore. The Arrow Value Recovery business model works on the basis of two main value propositions, one that is geared towards the businesses from which it collects and/or handles the obsolete equipment and another one that is geared towards small IT retailers and their end-customers. A third, but secondary, value proposition is that of offering parts and service for business customers who (need to) run outdated operating systems and platforms.

To the business clients that they collect the obsolete equipment from, Arrow Value Recovery offers to reduce risk and save cost by handling the reverse logistics, protecting and removing (sensitive) data (including the provision of a certificate that this has been done) and recovering of as much economical value at the end of the IT product lifecycle as possible (see also Arrow, 2017). To their network of around 3500 small, and often family owned, IT stores Arrow Value Recovery offers reliable, refurbished, computer systems that are backed by a 1 year (limited) warranty, something these IT stores and end-customers cannot get when buying second had equipment from private persons. The end-customers for these refurbished units are institutions (e.g. schools) or individuals who cannot afford, don't need, or don't want to spend money on, the latest and fastest IT equipment. The warranty is of the 'no-hassle swap' type, i.e., a broken unit is returned and exchanged for a working unit, as this is the easiest and most cost-effective way because of the stock and continuous inflow of obsolete IT equipment. If the refurbished IT equipment is exported outside Europe, for example to Africa, a number of extra refurbished and properly working units is supplied to cover the warranty in advance and prevent, then because of the distance suddenly costly, 'swapping'.

Whenever possible, Arrow Value Recovery tries to refurbish the obsolete products that it collects from business users before considering alternative options like recycling. The refurbishment process involves checking and repairing (if necessary) the hardware, performing a clean install of an operating system if so desired (preferred by Arrow Value Recovery but differs per customer and per country) and testing. Many OEMs (Original Equipment Manufacturers) require ITADs to be certified by them before the ITADs are allowed to refurbish their products and sell them as such. With prices of IT equipment and parts rapidly falling, however, replacement is often cheaper than repair and refurbishment is not always an option. For certain parts, like power supplies, the proceeds in scrap metal exceed the potential proceeds for the working, second-hand product.

The range of conditions in which Arrow Value Recovery receives their obsolete products varies greatly. Some of the products arriving at the Arrow Value Recovery facility need little to no work as they are new and have never been used. These can for example be customer returns from online retailers or RMAs (Returns to MAnufacturer). On the other side of the spectrum, Arrow Value Recovery receives obsolete IT equipment that is so old and/or damaged that it cannot be refurbished or contains no parts that can be reused. This old and/or damaged IT equipment is recycled at the materials level.

Next to falling equipment prices and OEM certification, Arrow Value Recovery faces a number of other challenges. According to Van Loon (Arrow Value Recovery Interview, 2012), there is a need for universally accepted standards and legislation pertaining to recovery processes as well as to what is considered waste. When used equipment that is shipped is considered waste somewhere along the line, this can have serious legal consequences. Another challenge lies in the way much of today's IT equipment, and particularly mobility devices, is constructed. Glued in batteries make it very difficult to properly treat (e.g., refurbish or recycle) obsolete devices. The last challenge mentioned here is not unique to the ITAD business, but rather of a more general business nature: that of competition trying to move in. Logistic companies, such as TNT and DHL, are trying to capture their own share of the reverse logistics market for obsolete products.

5.5.6 Loewe

The company visit to the Loewe, Kronach, Germany took place from 4-6 February, 2014.

Founded in 1923 in Berlin, Germany, Loewe is a manufacturer of premium television sets and audio equipment (Loewe, 2017). The company suffered badly from the financial crisis of 2008, and after three successive loss-making years, it filed for bankruptcy on the first of October 2013 (WSWS, 2017). Six months later, however, Loewe was rescued by the Stargate Capital investment group from Munich (Handelsblatt, 2017). Loewe's design and manufacturing facilities are located in Kronach, Germany. Subsidiaries of Loewe are located in the UK, France, Italy, Belgium and China (Hong-Kong).

Loewe sells (i.e., trades the ownership rights to) its products in its online shop and through a global network of independent dealers (Loewe, 2017; Loewe interview, 2014). Loewe products are intended to have a long product lifetime and Loewe communicates this to the public in its promotional materials and company website (Loewe, 2017). At its facilities in Kronach, the premium equipment Loewe manufactures is extensively tested before it is shipped out. Should a piece of equipment fail one of these tests, it is not scrapped but rather re-routed into the factory and repaired. Because of the intricate signal processing hardware that is used, much of it containing SMDs (Surface Mount Devices), specialized (and highly expensive) test and repair stations are required to diagnose and correct malfunctions. For repairs to Loewe equipment that already is in use by customers a two-step procedure is followed. First the local distributor/retailer checks whether the malfunction can be remedied by exchanging an electronics module. Only if this is not possible, the malfunctioning equipment is shipped to Loewe's Kronach facility to be repaired there. Loewe has a policy of keeping spare parts in stock for equipment up to seven years old to support the longevity of their products. This policy adds another layer of complexity to the already challenging task of manufacturing products with a potential for an extended lifetime in a fast-changing product category like consumer electronics. For the most important part of their television sets, the screen, Loewe is dependent on one of the few specialized manufacturers of these screens that there are in the world. As Loewe's production numbers are nowhere near high enough to influence the design and production cycle of these large screen manufacturers, it regularly happens that a specific type of screen that Loewe has chosen for one of its newly developed products is already out of production at the screen manufacturer before Loewe has launched its new product that contains this type of screen in the market. Loewe cannot easily switch to a different type of screen because a big part of Loewe's added value lies in the development and fine tuning of dedicated electronics that are able to get the best picture quality from a certain type of (otherwise standard) screen. As a result, Loewe needs to buy the total number of screens for the planned production run for a new model in advance and also the extra screens it expects to need to keep in stock to cater for seven years of potential repairs. As such, Loewe's commitment to product longevity increases the risk of doing business because these upfront investments add to the already high cost of developing a new product development.

As nobody wants to buy yesterday's technology at a premium, the fast pace of technological change in the television product category as a whole and the screen technology in particular, makes it virtually impossible for Loewe to re-use any parts from obsolete products. Obsolete Loewe products therefore go the same general route as most other consumer electronics and, after municipal collection, are bulk-processed at specialized waste processing plants. In ratio to the tonnage of new product Loewe puts out in the market, it has a legal obligation to take care of the processing of a certain tonnage of obsolete e-waste. At the time of the interview, this legal obligation actually made Loewe money as the proceeds from recovered metals exceeded to processing cost.

5.5.7 Tedrive

The company visit to Tedrive steering systems, Wülfrath, Germany, took place from 7-9 March, 2014.

Tedrive is a manufacturer and development partner of automotive steering systems (Tedrive, 2017a). The company was founded in 1924 and its headquarters is located in Wülfrath, Germany (Tedrive, 2017b). Tedrive has subsidiaries in Istanbul (Turkey), Shanghai (China), Wixom (USA) and Nabereznye Chelny (Russia). Since September 2016, Tedrive Steering has become part of the Knorr-Bremse Group (Tedrive, 2017a)

Tedrive design and manufacture (electronically controlled and hydraulically powered) recirculating ball steering gears for vehicles with high axle loads, such as buses and trucks, and rack-and-pinion systems for passenger cars (see also Tedrive, 2017a) (see figure 5.5.4).

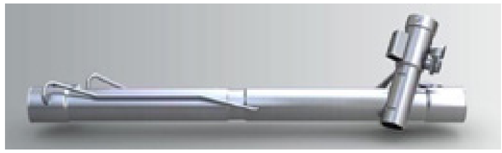


Figure 5.5.4: Tedrive steel housing. Image source: www.td-steering.com/steel-Housing.html.

What sets Tedrive steering systems apart from other steering systems on the market is the steel housing they use for their steering systems and for which they were awarded the German Steel Innovation Prize (Tedrive, 2017c). The steel housing is stronger, stiffer and more durable than it conventional aluminium counterparts. Because the steel housings are manufactured from rods, sheet and tubing in CNC controlled processes their production does not require the expensive moulds that cast aluminium housings require. This allows for greater flexibility, making it possible for Tedrive to manufacture housings that are tailor made to

5

different car platforms, even when the production runs are relatively low. Additional advantages of using a steel over an aluminium housing are: greater steering precision and a reduced number of individual parts. The high commercial value of steering systems in general, the high durability and resistance to corrosion in combination with the reduced number of parts make the steel steering systems an ideal candidate for remanufacturing.

Tedrive have therefore set up a remanufacturing department at their factory in Wülfrath where a portion of their steel steering systems are remanufactured. Tedrive get the used, obsolete steering systems, called *dirty cores* in remanufacturing jargon, from (dealer) car workshops that are owned by or operate for the car brands that Tedrive manufacture their steering systems. The dirty cores are supplied to Tedrive loosely stacked in metal crates. This particular way of transporting the dirty cores causes additional damage to the dirty cores, rendering some of them unusable for remanufacturing. This poses no problem to Tedrive as, at the time of the interview, the dirty cores where supplied without further cost to Tedrive and the potential supply was bigger that the remanufacturing capacity of Tedrive.

The remanufacturing process starts with an initial check of the dirty cores in which those cores that are too damaged are discarded. The dirty cores that pass the initial check are next taken apart and thoroughly inspected at part level for correctness of geometry, wear, defects and cracks. In the process, the parts originating from the various dirty cores are cleaned and sorted by part type. Parts from one individual dirty core do not necessarily stay and/or end up together in the remanufacturing process. In the remanufacturing process, bearings and seals are replaced and new parts are added where necessary.

Before the remanufactured units are released for use, they are individually tested to ensure their compliance to the exact same specifications as newly manufactured units. The rigorous process and testing ensures that both the functional and cosmetic properties of the remanufactured units are virtually identical to those of units manufactured from all new materials and components. Because at present it is not allowed by law to use remanufactured components in the production of products labelled as 'new', the remanufactured units are permanently marked by stamping an 'R' (for Remanufactured) over the original engraved Q-code that represented the serial number of the dirty core, or obsolete unit, in effect forcing Tedrive to lower the perceived use value of their remanufactured units on purpose.

Tedrive has both a product that is well suited to lifetime extension and a process in place to extend the lifetime of the product without lowering its specifications. With regard to their remanufacturing business, Tedrive, however, face a number of challenges that limit the commercial opportunities and potential upscaling of Tedrive remanufacturing process.

Remanufacturing is not commercially viable for every type of steering system. As remanufactured units cannot be used in the production of new cars but only for repairs, the number of cars of a certain brand and model, and the duration of the period that a particular model is on the market, are important factors in determining whether there will be sufficient demand for remanufactured units.

Under the conditions of Tedrive's current supply agreement(s) of dirty cores, i.e., unlimited and free supply from car workshops affiliated with their clients' brand, Tedrive is not allowed to sell remanufactured units to third parties, such as non-brand-affiliated car workshops).

Lastly, at the time of the interview, some countries did not allow the import of remanufactured products. Tedrive has (partly) solved this problem by setting up local remanufacturing businesses in some of those countries.

5.5.8 Comparison of Findings from Company Interviews and Visits

This section discusses the similarities, differences, common or unique challenges as observed in the results from the above interviews and company visits.

Similarities

Although they operate in a wide variety of sectors, most of the companies (with the exception of Arrow Value Recovery, see below) manufacture products that are considered of high grade and high quality in their respective product categories. The products they manufacture stand out because of innovative use of (proprietary) technology and/or quality of workmanship, justifying the higher than average price in the market. Longevity, not only of their products but also as an attitude towards doing business, is an integral part of the brand identity of these companies. As such, the provision of service and after-sales support (e.g. warranty) long after the moment of the original sales transaction is important to them. All of the companies that were interviewed traded their products by selling the rights of ownership to them, either to an end-user or to a company that would lease out their products. At the time of the interview, of the seven companies interviewed, only BMA Ergonomics experimented with handling the leasing out (i.e., trading rights of use) of their own products themselves.

Differences

Despite these many similarities, significant differences between the various business models can also be observed. The business model used by Océ for example, is the only one that combines products with a long lifetime potential with dedicated short-lived consumables. Although currently not circular, the Océ business model type at this point closely resembles a Classic Long Life Hybrid or Access Hybrid business model type as discussed in section 4.7.1, as in these business model types, the long-lived product is only a secondary source of revenue, serving as an enabler for the primary source of revenue, i.e., the provision of (maintenance) service and supplies (e.g. toner and paper). Three of the seven companies that were interviewed, i.e., Miele, Loewe and Eastpak do not take back obsolete products after their initial use cycle. The remaining four, i.e., Océ, BMA Ergonomics, Arrow Value Recovery and Tedrive do, and after performing interventions for preserving product integrity on these obsolete products put their products back on the market for another use cycle (or more).

The business model of Arrow Value Recovery stands out as it is a model for preserving product integrity of the type that creates revenue from taking in products and extending the lifetime of products it has not previously manufactured, i.e., the non-circular Gap Exploiter type (see sub-section 4.7.2)

Common Challenges

The interviews make clear that companies who do perform interventions for preserving product integrity face three key common challenges. The first is that it is difficult for manufacturers to get their products back once they have transferred the rights of ownership to them (e.g. Océ and BMA Ergonomics). The second challenge is that even if companies can acquire obsolete products, they often have no control over the state of the obsolete products they receive (e.g. Arrow Value Recovery and Tedrive). The third challenge lies in the (lack of) rules, regulations and standards that are used to regulate obsolete and recovered products (e.g., Océ, Arrow Value Recovery and Tedrive) and that result in assigning to little e.g. qualifying valuable presources as 'waste' (Arrow Value Recovery) or not enough (e.g. Qualifying

5

remanufactured products as 'not new' (Océ and Tedrive) economic value to presources and/or recovered products.

Company or Product Type Specific Challenges

Two of the company interviews presented challenges that, although unique within the limited set of seven companies visited, are worth mentioning here because of their nature they could well apply to other instances in industry. The first of these challenges lies in the (lack of control over the) rapid pace of innovation of core technology used in a particular product, as for example experienced by Loewe with its LCD screens. Such a high rate of change in the functional specifications of a major product component makes it virtually impossible for a company to recover obsolete products at product level and successfully put them back onto the market after their initial use cycle. The second challenge lies in contractual limitations, as for example are part of Tedrive's agreement with its customer, that can limit the economic value a company can capture from its remanufactured products.

The interviews provided a number of examples of business models that capture value from long or extended product lifetime or preserving product integrity by transferring the rights of ownership to tangible products with a potential for a long lifetime. They yielded several new and important insights in the workings and challenges of business models for extended product lifetime, but at the same time made clear that none of the interviewed companies at the time of the interview had a business model that could be labelled as a circular business model for preserving product integrity, as none of the business models met all three requirements as proposed in section 4.5. Although the business models of for example Miele and Eastpak meet both the first and second requirements (see section 4.4) as they create revenue from tangible products and are constructed in such a way that extended product lifetimes contribute positively and structurally to the continuity, revenue and profit, they are not circular as they do not meet all criteria for the third requirement. Although they both have control over the design of the tangible product, they do not make use of presources to a maximum extent nor do they retain or have arrangements in place to take back, economic control over their products and presources.

5.6 INTRODUCING THE CONCEPT OF MANAGING OBSOLESCENCE: A CROSS-DISCIPLINARY APPROACH FOR MAXIMIZING BUSINESS MODEL CIRCULARITY

The previous sections made clear that vast majority of the problems with regard to maximizing business model circularity (i.e., managing the recovery process and consistently implementing the Inertia Principle) arise from the lack of control over the flow of obsolete products. With rising uncertainty about the variations in quantity and quality of the flow of returns over time (e.g. Guide Jr. et al., 2000), it becomes increasingly difficult to determine the (type of) potential for preserving product integrity that should be designed and manufactured into a product, as this will strongly depend on the particular recovery scenario that is followed.

As argued in chapter 2, the onset of obsolescence is caused by a loss of perceived use value of a product, that may or may not be triggered by a lack or loss of functionality. Industrial design, as explained in chapter 3, can therefore only design a potential for an extended product lifetime into a tangible product, but in and by itself has no control over whether this extended lifetime potential is actually realised or not.

The view taken by the thesis that the perceived use value of a product over time is determined by more than the *"attributes formed through design and manufacture"* (Cooper, 2010, p. 8) is corroborated in the business sciences literature on relationship marketing. Relationship marketing is, in contrast to 'conventional' marketing focus on one-time transactions, aimed at *"attracting, maintaining and … enhancing customer relationships* [over time]*"* (Berry (1983) as cited in Egan, 2011, p. 35). Building on Zeithaml, i.e., *"perceived value is the customer's overall assessment of the utility of a product based on a perception of what is received and what is given"* (Zeithaml, 1988, p. 14), Grönroos (1997) remarked that *"in a relational context* [e.g. product-service based value propositions] *the offering includes both a core* [tangible] *product and additional services of various kinds"* (p. 412). The newly proposed approach for controlling the fluctuations in quality and quantity of the flow of obsolete products that is proposed here is therefore aimed at controlling the (non)occurrence and reversal of obsolescence by managing the *perceived use value associated with the tangible product* (Zeithaml, 1988) over time instead of merely the condition and/or functionality of the tangible product over time. Contrary to existing approaches for affecting the flow of obsolete products, such as planned obsolescence, that were predominantly devised to only benefit manufacturers, the proposed new approach for controlling the flow of obsolete products must also benefit users (i.e., provide perceived use value) in order to find acceptance. Even if not in equal measure, then at least to such an extent that users will allow, and preferable want, the manufacturer to exert the level of control over the flow of (obsolete) products that is required for maximizing business model circularity in a circular economy. The newly proposed concept, 'managing obsolescence', is therefore cross-disciplinary, bridging the domains of the business sciences and (sustainable) industrial design. The thesis defines the concept of managing obsolescence as follows:

Managing obsolescence is the practice of predetermining, controlling and communicating to the user the point in time when a product will become obsolete to enhance the economic and environmental efficiency of recovery processes with the aim of maximizing business model circularity.

Managing obsolescence will allow circular business models for preserving product integrity to maximize their control over when and how their products become presources and are subsequently turned back into products.

With managing obsolescence, the onset of obsolescence - at which point the products will be returned to (a third party contracted by) the original manufacturer for recovery - is controlled by predetermining and managing the perceived value of the product over time. As the value proposition of a circular business model for preserving product integrity is always a combination of a tangible product and an intangible service component, both the design of the tangible product and the intangible service component will need to support the predetermination and communication to the user(s) of the point(s) in time when a product will become obsolete. As a tangible product can go through multiple use cycles and be subjected to various interventions for preserving product integrity over its lifetime, each leaving the tangible product in a different state (e.g., 'upgraded', 'repaired', 'refurbished', or 'new' in case of remanufacturing (see chapter 2)), managing obsolescence can be seen as *preserving product integrity by aligning value propositions with product states over time and ahead of time.* An essential element of managing obsolescence is that information regarding the product lifetime (either the total product lifetime or the length and/or number of the use cycles that can reasonably be expected) is made known to the user (and/or buyer) of the product before the moment of transaction (either a transfer of 'rights of ownership' or 'rights of use'), for only then can users (and/or buyers) arrive at an accurate assessment of the perceived value of the product under consideration.

The primary objective of managing obsolescence in a circular economy is to enable circular business models for preserving product integrity to create value propositions built around tangible products that are created from presources whose added economic value has been preserved to the maximum extent, at lower (or at least identical) environmental and economic cost as compared to creating the same value proposition built around products created from virgin resources. In order to achieve short and long-term business goals (Stout, 2017; Tukker et al., 2006; Heiskanen, 1996), managing obsolescence should furthermore offer users perceived use value at an exchange value that is lower (or identical) than that of the same perceived use value created from (virgin) resources.

Successful management of obsolescence in a circular economy requires the matching of environmental-, business- and user interests within the existing legislative and regulatory frameworks and would therefore require the management of circular business models for preserving to make an accurate assessment of and plan:

a. The incentive (value proposition) needed to persuade the user or customer to accept the occurrence of managed obsolescence;
b. The incentive (value proposition) needed to persuade the user or customer to return the obsolete product;
c. The incentive (value proposition) needed to persuade the user or customer to accept a recovered product or a product containing recovered presources;
d. By what mechanism obsolescence is to be triggered;
e. The time to, or between, occurrence(s) of obsolescence, e.g. the optimal product lifetime (Burns, 2010; Van Nes & Cramer, 2005; Charter & Tischner, 2001; Tischner et al., 2000) given the economic, environmental, legislative and regulatory conditions present;
f. The number of times obsolescence is to occur, e.g. the optimal number of use cycles and total product lifetime, given the economic, environmental, legislative and regulatory conditions present;
g. The number, type and order of intervention(s) for preserving product integrity and added economic value to be applied in order to maximize the amount of added value preserved, given the economic, environmental, legislative and regulatory conditions present;
h. The additional (p)resources needed for the collection of the obsolete product and for the redistribution after recovery of the recovered product or a product containing recovered presources;

It should be noted that in order to preserve the maximum amount of added economic value for as long as possible over the total product lifecycle, managed obsolescence can be used to help persuade users to hold on to their current product a little while longer but also to help persuade users to part with their current product at a predetermined point in the lifecycle of the product. Managing obsolescence and creating viable value propositions over time can require products to be returned to the manufacturer after a specific period of use, for example to limit wear and tear and thus ensure the product remains eligible for efficient and effective refurbishment, both from an environmental and an economic perspective. In some instances, this could mean that obsolescence has to be induced instead of resisted, postponed or reversed. These (design) interventions to induce obsolescence are considered of a secondary nature in a circular economy, e.g. employed to support the primary, interventions aimed at product life extension. We deem these (design) interventions to lie outside the scope if this thesis and as such they are not further discussed here. Incentives and options for inducing obsolescence (although most of them not developed with the intent to extend product lifetimes) are well-known in the context of a linear economy and have been extensively covered elsewhere in the conventional, linear economy based, design, engineering and business literature (see for example: Guiltinan, 2008).

In the design of the other elements of the value proposition for each use cycle, other types of interventions, such as the choice of type of rights traded and amount and type of intangible services provided (i.e., the particular type of circular business model for preserving product integrity) but also certain buy-back or trade-in schemes, can be employed.

An Example of Managing Obsolescence: A Smartphone

To illustrate the workings of the newly introduced concept, an example of managing obsolescence as it could play out for a smartphone is presented.

A smartphone, if refurbished relatively early in its lifecycle, may still be reintroduced into the market as part of a viable value proposition (e.g. BestBuy, 2017; Leapp, 2017; Refurbishedmobilephones, 2017). If left with its user without interventions for preserving product integrity for too long, however, it can only be recovered at 'material' level (Van Weelden et al., 2016). As refurbishment is *"a promising strategy that enables high original value retention"* (Van Weelden et al., 2016, p. 743) because it *"does not require complete dismantling of products"* (Van Weelden et al., 2016, p.743), it is likely that from environmental as well as from a business-economic perspective, one or more refurbishment interventions (ultimately followed by recycling) in this example are preferable to immediately resorting to recycling, i.e., recovery at 'material' level.

A typical scenario for a new smartphone in our current linear economy is that, without interventions for preserving product integrity, it becomes obsolete after only two years of use (Al-Jumeily et al., 2014). By that time the functionality of the unit is limited as compared to newer models and battery capacity has become insufficient (Al-Jumeily et al., 2014). Furthermore, the exterior often shows signs of use. Software updates (i.e., an intervention for preserving product integrity by postponing obsolescence) in some instances help to mitigate part of the problem. The potential effects of software updates, however, are limited. Although they can be used to keep a number of software functions current, improve battery management and image processing, they cannot be used to alter the maximum battery capacity, camera resolution or processor speed that are fixed by the smartphones hardware setup. In the end, the often prohibitively high cost of battery replacement, combined with the limited specifications, worn exterior and, not in the least, the value propositions offered built around newer smartphone models (Al-Jumeily et al., 2014), many times lead to the older smartphone ending up in a drawer, where it 'hibernates' (Oswald & Reller, 2011, Al-Jumeily et al., 2014) until it is finally discarded and ends up as e-waste some months or even years later. At that point, in most instances the only added economic value left to be recovered from the unit is the economic value of the materials that can be salvaged from the unit in recovery processes at the 'material' level. Most smartphones are currently not designed for recovery at end-product level (Van Weelden et al., 2016) after several years of use, and few users or businesses are interested in acquiring an outdated and worn smartphone because of perceived risks of lack of performance and the looming threat of obsolescence (van Weelden et al., 2016).

Managing obsolescence in a circular economy, however, could result in a different scenario. If the first user of the new smartphone would be required by contract to return the used smartphone to the distributor/manufacturer after two years of use, it would still be sufficiently modern to be refurbished (e.g. its outsides brushed up, its software and/or firmware updated, and its battery replaced if need be) and redistributed in the smartphone market as part of a different value proposition. The new value proposition could entail a refurbished smartphone under warranty and with a lower cost data plan targeted at a different, less demanding customer segment (van Weelden et al., 2016). With a different user and a different value proposition the smartphone could well support another two years of active use. One could even speculate that, as the rate of changes in functionality slows down as the 'smartphone' product category matures, a third use cycle of one or two years would be feasible with only limited interventions for preserving product integrity, until eventually the only added economic value left to be recovered would be that of its constituent materials.

5.7 DISCUSSION AND CONCLUSIONS

The newly presented concept of managing obsolescence builds on and combines the insights gained from existing approaches for affecting the flow of obsolete products. As a result, managing obsolescence expands on, the existing approaches for affecting the flow of obsolete products in a number of ways. Firstly, managing obsolescence is driven by business-economic and by environmental motives that go beyond health and safety and compliance, instead of driven by either business-economic or environmental motives as are many of the existing approaches. Secondly, managing obsolescence is explicitly aimed at minimizing (instead of maximizing) the replacement rate of products. It enables manufacturers to maximize their level of control, both over the timing and reasons for the onset of obsolescence of their tangible products and over the timing and types of interventions used for their recovery, where the existing approaches - at best - enabled manufacturers to affect these and/or mitigate (e.g. life cycle management and planned for obsolescence) their effects. Thirdly, managing obsolescence maximizes the level of control the flow of obsolete products to the direct and mutual benefit of both manufacturers and users and does so in a manner that is clear and transparent at the moment of transaction as, for example, the duration of use cycles is communicated in advance as part of the value proposition, for example in a similar way as with the take-back agreements (e.g. BMA Ergonomics) and lease contracts (e.g. Océ) mentioned in the company interviews.

In its ideal form, the new level of control over the onset and reversal of obsolescence as offered by managing obsolescence would enable circular business models for preserving product integrity to create a perfect match between the actions required for achieving environmental business objectives and those for achieving economic business objectives, allowing companies to maximize their business model circularity in a circular economy.

In practice, however, it might not always be feasible to bring environmental and economic objectives in line in a real-world circular economy. Pending conventions for economic valuation (Ayres & Ayres, 1996; Hanemann, 1994; Sirkin & Ten Houten, 1994) that are fully capable of expressing environmental benefits and damages in economic terms for example, interventions for preserving product integrity required to best meet the absolute environmental goals of a circular economy will only be in alignment with the actions required to best meet business-economic goals some of the time. At other times, they will work against each other to a greater or lesser extent. Careful consideration of the environmental and economic aspects over the entire product lifecycle is then required to reach a decision with regard to the product lifecycle scenario that can be considered the best compromise between the optimal scenario from an environmental and the optimal scenario from an economic point of view. In a real-world scenario, the success of managing obsolescence will furthermore depend on the extent to which industrial designers and other business professionals (e.g. marketing professionals) will be able to predict the onset of obsolescence, both with regard to the changing future needs of customers and the elusive *"path*[s] *of technological innovation"* (Sood et al., 2012, p. 964) as mentioned in sub-section 5.3.2.

Chapter 5 started by establishing the need and purpose (i.e., maximizing business model circularity) for maximizing the level of control of manufacturers over the (quality and quantity of) the flow of obsolete products or presources in a circular economy. After discussing the potential barriers to controlling the flow of obsolete products, we reviewed the literature for existing approaches to control the flow of obsolete products. We found the need to affect and control the flow of obsolete products to be clearly articulated in the literature and that both the need for control and the required level of control are expected to increase in a circular economy. We also found the current literature to contain a number of approaches for *affecting* the flow of obsolete products but none for *controlling* the flow of obsolete products. Many of the approaches for affecting the flow of obsolete products described in the literature were developed to serve either business-economic or environmental goals and virtually none of the existing approaches are aimed to directly benefit the user. In response, we developed the concept of managing obsolescence as a cross-disciplinary approach, i.e., involving both product design and business management and design, for controlling the flow of obsolete products in a circular economy. We defined the concept of managing obsolescence as the practice of predetermining, controlling and communicating to the user the point in time when a product will become obsolete to enhance the economic and environmental efficiency of recovery processes with the aim of maximizing business model circularity.

The essence of managing obsolescence lies in the fact that successfully preserving product integrity is not achieved by preserving functionality over time (i.e., a tangible product design and engineering task) but instead relies on preserving perceived value over time (i.e., a combined task of tangible product design and engineering and the marketing function).

For industrial designers, managing obsolescence means they have to design a product for one use-cycle or multiple use cycles of pre-determined duration, and/or for use by multiple users, *over a product's entire lifetime time, ahead of time*. For business professionals, managing obsolescence means they have to develop, support and communicate multiple value propositions, potentially for multiple users, *over a product's entire lifetime time, ahead of time.* By explicitly focussing on the entire value proposition, i.e., on both the tangible and intangible components that together help create the user's perception of value, the concept of managing obsolescence is able to leverage the notion that the onset of obsolescence and the recovery from obsolescence are not solely determined by the properties of the tangible product, but for example also includes changes to the various *"elements of the marketing mix"* (PDMA, 2017), e.g. the business model type the product is embedded in. As such, managing obsolescence allows for, and makes use of, the widest possible solution space within the span of control of manufactures (excluding for example altering national or international legislation or altering the conventions for economic valuation) for creating highly product type dependent solutions for controlling the flow of obsolete products to a maximum extent.

REFERENCES CHAPTER 5: MANAGING OBSOLESCENCE

Adamson, G. (2003). Industrial Strength Design, How Brooks Stevens Shaped Your World. Cambridge, MA, U.S.A.: the MIT press.

Al-Jumeily, D., Hussain, A., & Macilwee, S. (2014). Investigation of green disposal of smartphones. *Advanced Materials Research, 1051*, 622-626.

Alting, L. & Brøbech Legarth, J. (1995). Life Cycle Engineering and Design. In *CIRP Annals-Manufacturing Technology, 44*(2), 569-580**.**

Anderson, E., Lin, S., Simester, D., & Tucker, C. (2015). Harbingers of failure. *Journal of Marketing Research*, *52*(5), 580-592.

Arrow (2016). *Arrow annual report 2016*. Retrieved April 21st, 2017 from https://www.arrow.com/en/media-center/annual-report-2016.

Arrow (2017). Arrow Value Recovery company website: https://www.arrow.com/s-tech/

Assemblée Nationale, (2015). *Code de la Consommation - Article L213-4-1*. Retrieved June 1st, 2017 from: www.legifrance.gouv.fr/affichCodeArticle.docidTexte=LEGITEXT000006069565&idArticle=LEGIARTI000031053376.

Atasu, A., Guide Jr., V. D. R., & Van Wasenhove, L. N. (2008). Product Reuse Economics in Closed-Loop Supply Chain Research. *Production and Operations Management 17*(5), 483-496.

Audiotranskription (2017). F5transkript for Mac. Audiotranskription company website: www.audiotranskription.de.

Ayres, R.U., Ayres, L.W., (1996). *Industrial Ecology: Towards Closing the Material Cycle*. Cheltenham, UK: Edward Elgar Publishing Limited.

Bakker, C.A., Wang, F., Huisman, J., & Den Hollander, M.C. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production 69*, 10-16.

Bartels, B., Ermel, U., Sandborn, P., Pecht, M. (2012). *Strategies to the Prediction, Mitigation and Management of Product Obsolescence*. Hoboken, NJ, USA: John Wiley & Sons Inc.

Berry, L. L. (1983). Relationship marketing. In Berry, L.L., Shostack, G.L. & Upsay, G.D. (Eds.), *Emerging Perspectives on Service Marketing* (pp. 25-28). Chicago, IL, USA: American Marketing Association.

BestBuy (2017). *Refurbished Phones.* Retrieved June 3rd, 2017 from www.bestbuy.com/site/pre-owned-phones/refurbished-phones/pcm-cat356000050007.c?id=pcmcat356000050007.

Beuren, F. H., Ferreira, M. G. G., & Miguel, P. A. C. (2013). Product-service systems: a literature review on integrated products and services. *Journal of Cleaner Production*, *47*, 222-231.

BMA (2017). About BMA Ergonomics. Retrieved April 19th, 2017 from: www.bma-ergonomics.com/en/about-bma-ergonomics/.

Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. *British journal of management*, *11*(1), 1-15.

Box, J. M. F. (1983). Extending product lifetime: Prospects and opportunities. *European Journal of Marketing, 17*(4), 34–49.

Burns, B. (2010). Re-evaluating Obsolescence and Planning for It. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 39-60). Farnham, Surrey, UK: Gower Publishing Limited.

Canon (2016). *Cannon Annual Report 2016*. Retrieved April 20th, 2017 from: www.canon.com/ir/annual/2016/canon-annual-report-2016.pdf.

Canon (2017a). History. Retrieved April 21st, 2017 from: https://lfpp.csa.canon.com/main/product_group.jsp?WebLogicSession=L1hmTwKJR4jJnp1wJzpjX5Br4PwRCnQhw9TRVHmXT1PYqK6BLY1v!591701672&FOLDER%3C%3Efolder_id=2534374302041413&bmUID=1408289633771.

Canon (2017b). Canon and Océ to create global leader in printing industry. Retrieved April 21st, 2017 from: http://global.canon/en/news/2009/nov16e.html.

Charter M., & Tischner U. (2001). Sustainable Solutions. Developing Products and Services for the Future. Sheffield, UK: Greenleaf.

Cooper, T. (2010). The Significance of Product Longevity. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 3-36). Farnham, Surrey, UK: Gower Publishing Limited.

Daily, G. C., Söderqvist, T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P. R., & Levin, S. (2000). The value of nature and the nature of value. *Science*, *289*(5478), 395-396.

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

Despeisse, M., Kishita, Y., Nakano, M., & Barwood, M. (2015). Towards a circular economy for end-of-life vehicles: A comparative study UK–Japan. *Procedia CIRP*, *29*, 668-673.

DiCiccoBloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical education*, *40*(4), 314-321.

Eastpak (2017). Eastpak company website: https://www.eastpak.com.

Egan, J. (2011). *Relationship Marketing – exploring relational strategies in marketing* (4th ed.). Harlow, Essex, UK: Pearson Education Limited.

EMF (Ellen MacArthur Foundation) (2012). *Towards the Circular Economy Vol. 1 - An Economic and Business Rationale for an Accelerated Transition.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.

EMF (2013). *Towards the Circular Economy Vol. 2 - Opportunities for the Consumer Goods Sector.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.

EMF (2014). *Towards the Circular Economy Vol. 3 - Accelerating the scale-up across global supply chains*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.

EMF (2015). *Growth Within: a circular economy*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.

Erler, S., & Rieger, E. (2016). Product Evolvement through Entirely Scheduled Lifecycles. *Procedia CIRP*, *48*, 79-83.

Evans, S., Partidário, P. J., & Lambert, J. (2007). Industrialization as a key element of sustainable product-service solutions. *International Journal of Production Research*, *45*(18-19), 4225-4246.

Ferguson, N., & Browne, J. (2001). Issues in end-of-life product recovery and reverse logistics. *Production Planning & Control*, *12*(5), 534-547.

Fine, B., & Saad-Filho, A. (2016). *Marx's Capital.* London, UK: Pluto Press.

Fleischmann, M., Bloemhoff-Ruwaard, J. M., Dekker, R., Van der Laan, E., Van Nunen, J. A. E. E., & Van Wassenhove, L. N. (1997). Quantitive Models for Reverse Logistics: A Review. *European Journal of Operational Research, 103*, 1-17.

Fukushige, S., Yamamoto, K., & Umeda, Y. (2012). Lifecycle scenario design for product end-of-life strategy. *Journal of Remanufacturing 2*(1), 1-15.

Githens, G. (2007). Product lifecycle management: Driving the next generation of lean thinking by Michael Grieves. *Journal of Product Innovation Management, 24*(3), 278-280.

Golder, P.N. & Tellis, G. J. (2004). Growing, Growing, Gone: Cascades, Diffusion, and Turning Points in the Product Life Cycle. Marketing Science, 23(2), 207-218.

Gómez-Baggethun, E., & Ruiz-Pérez, M. (2011). Economic valuation and the commodification of ecosystem services. *Progress in Physical Geography*, *35*(5), 613-628.

Graedel, T. E., & Allenby, B. R. (2003). *Industrial Ecology* (2nd ed.). Upper Saddle River, New Jersey, USA: Pearson Education, Inc.

Grieves, M. (2005). *Product Lifecycle Management: Driving the Next Generation of Lean Thinking.* New York, NY, USA: McGraw Hill.

Grönroos, C. (1997). Valuedriven relational marketing: from products to resources and competencies. *Journal of marketing management*, *13*(5), 407-419.

Guide Jr., V. D. R. (2000). Production planning and control for remanufacturing: industry practice and research needs. *Journal of Operations Management 18*(4), 467-483.

Guide Jr., V. D. R., Harrison, T. P., & Van Wassenhove, L. N. (2003). The challenge of closed-loop supply chains. *Interfaces, 33*(6), 3-6.

Guide Jr., V. D. R., Jayaraman, V., Srivastava, R., Benton, W. C. (2000). Supply-Chain Management for Recoverable Manufacturing Systems. *Interfaces, 30*, 125-142.

Guide Jr., V. D. R., Kraus, M. E., & Srivastava, R. (1997). Scheduling policies for remanufacturing. *International Journal of Production Economics 48*(2), 187-204.

Guide Jr., V. D. R., & Srivastava, R. (1998). Inventory buffers in recoverable manufacturing. *Journal of Operations Management 16*(5), 551-568.

Guide Jr., V. D. R. & Van Wassenhove, L. N. (2005). Hewlett-Packard Company Unlocks the Value Potential from Time-Sensitive Returns. *Interfaces 35*(4), 281-293.

Guide Jr., V. D. R., & Van Wassenhove, L. N. (2009). OR FORUM—The evolution of closed-loop supply chain research. *Operations research, 57*(1), 10-18.

Guiltinan, J. (2009). Creative Destruction and Destructive Creations: Environmental Ethics and Planned Obsolescence. *Journal of Business Ethics, 89*, 19-28.

5

Hagen-Zanker, J., & Mallett, R. (2013). *How to do a rigorous, evidence-focused literature review in international development, A Guidance Note.* London: Overseas Development Institute.
Handelsblatt (2017). Münchener Investor übernimmt Loewe. Retrieved April 21st, 2017 from: www.handelsblatt.com/unternehmen/handel-konsumgueter/tv-hersteller-gerettet-muenchener-investor-uebernimmt-loewe/9653396.html.
Hanemann, W. M., (1994). Valuing the Environment Through Contingent Valuation. *Journal of Economic Perspectives 8*(4), 19–43.
Hart, C. (2011). *Doing a literature review: Releasing the social science research imagination.* London, UK: SAGE.
Hatcher, G.D., Ijomah, W.L., & Windmill, J.F.C. (2011). Design for remanufacture: a literature review and further research needs. *Journal of Cleaner Production, 19*, 2004-2014.
Heiskanen, E. (1996). *Conditions for Product Life Extension.* National Consumer Research Centre Working Papers 23.
Herman, S. (1981). The uses and abuses of Roman law texts. *The American Journal of Comparative Law*, *29*(4), 671-690.
Inoue, M., Yamada, S., Yamada, T., & Bracke, S. (2016). Product upgradability for satisfying future performance, low price and environmental loads, and manufacturer profitability throughout the lifecycle. In Seliger, G. & Krüger, J. (Eds.), *Proceedings of the 23rd CIRP Conference on Life Cycle Engineering 48* (pp. 40-44).
Jayaraman, V. (2005). Production Planning for Closed-Loop Supply Chains with Product Recovery and Reuse: an Analytical Approach. *International Journal of Production Research* 44(5), 981-998.
Keoleian, G. A., & Menerey, D. (1993). *Life cycle design guidance manual: Environmental requirements and the product system.* Document reference: EPA600/R-92/226. Ann Arbor, MI, USA: National Pollution Prevention Center, University of Michigan.
Kim, B. (2003). Managing the transition of technology life cycle. *Technovation, 23*, 371–381.
Kim, H.C., Keoleian, G.A. & Yuhta, A.H. (2006). Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost. *Energy Policy, 34*, 2310-2323.
King, A. M., & Burgess, S. C. (2005). The development of a remanufacturing platform design: a strategic response to the Directive on Waste Electrical and Electronic Equipment. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *219*(8), 623-631.
Kurilova-Palisaitiene, J., Lindkvist, L., & Sundin, E. (2015). Towards facilitating circular product life-cycle information flow via remanufacturing. *Procedia Cirp*, *29*, 780-785.
Leapp (2017). Leapp company webite: https://leapp.nl
Lifset, R. & Graedel, T. E. (2002). Industrial ecology: goals and definitions. In Ayres, R.U. (Ed.), *A handbook of industrial ecology* (pp. 3-15). Cheltenham, UK: Edward Elgar publishing.
Linder, M., & Williander, M. (2015). Circular business model innovation: inherent uncertainties. *Business Strategy and the Environment, 26*(2), 182-196.
Loewe (2017). The company. Retrieved April 21st, 2017 from: https://www.loewe.tv/company.html.
London, B. (1932). Ending the Depression Through Planned Obsolescence. Retrieved November 23rd , 2017 from https://nl.wikipedia.org/wiki/Bestand:London_(1932)_ Ending_the_depression_through_planned_obsolescence.pdf
Malone, T. W., Weill, P., Lai, R. K., D'Urso, V. T., Herman, G., Apel, T. G., & Woerner, S. (2006). *Do some business models perform better than others*? Retrieved November 20th, 2017 from https://mpra.ub.uni-muenchen.de/4751/1/MPRA_paper_4751.pdf.
Miele (2013). *Sustainability Report 2013*. Retrieved April 18th, 2017 from www5.miele.nl/ apps/vg/nl/miele/mielea02.nsf/0e87ea0c369c2704c12568ac-005c1831/47894c8c4f828713c1257b960050faaf/$-FILE/Sustainability_Report_2013_English.pdf.
Miele (2016). *Business Report 2015/2016*. Retrieved April 18th, 2017 from www.miele.nl/m/downloads-324.htm.
Miele (2017a). Miele company website: www.miele.com/en/com/index.htm.
Miele (2017b). *Miele Laundrette.* Retrieved April 18th, 2017 from www5.miele.nl/apps/vg/nl/miele/Miele001.nsf/LookUpPage/HomepageLaundrette?OpenDocument/.
Navin-Chandra, D. (1994). The Recovery Problem in Product Design. *Journal of Engineering Design, 5*(1), 65–86.
NRC (2011). *Miele blijft draaien op kwaliteit*. (Tr.: Quality keeps Miele going). NRC newspaper, October 6th. Retrieved November 23rd, 2017 from https://www.nrc.nl/nieuws/ 2011/10/06/miele-blijft-draaien-op-kwaliteit-12038761-a483106.
Oakdene Hollins Ltd. (2007). *An Analysis of the Spectrum of Re-use*. Aylesbury, UK: Oakdene Hollins Limited. (Document reference: DEFR02 089 Reuse Review.doc).
Océ (2017b). About Océ. Retrieved April 19th, 2017 from http://oce.com/company/.
Océ (2017c). Innovative by Nature. Retrieved April 19th, 2017 from http://oce.com/innovation/.
Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation*. Hoboken, NJ, USA: John Wiley & Sons.
Oswald, I. & Reller, A. (2011). E-waste: A story of trashing, trading, and valuable resources. *GAIA Ökologische Perspektiven für Wissenschaft und Gesellschaft, 20*(1), 41–47.

PDMA (2017). *The PDMA Glossary for New Product Development*. Retrieved June 14th, 2017 from www.pdma.org/p/cm/ld/fid=360#P.
Reim, W., Parida, V. & Örtqvist, D. (2015). Product-Service Systems (PSS) business models and tactics - a systematic literature review. *Journal of Cleaner Production, 97*, 61-75.
Refurbishedmobilephones (2017). *Refurbished Mobile Phones for Vodafone.* Retrieved June 3rd, 2017 from www.refurbishedmobilephones.co.uk/refurbished-mobile-phones-for-vodafone.
ResCom (2017). ResCom project website: http://www.rescoms.eu/.
Ricoh (2017). Ricoh company website: www.ricoh.com.
Rojo, F., Roy, R., & Shebab, E. (2010). Obsolescence management for long-life contracts: state of the art and future trends. *International Journal of Advanced Manufacturing Technology 49*, 1235-125.
Rose, C. M. (2000). *Design for environment: a method for formulating product end-of-life strategies* (Vol. 185). Stanford, CA, USA: Stanford University.
Saaksvuori, A. & Immonen, A. (2005). *Product Lifecycle Management* (2nd ed.). Berlin-Heidelberg, Germany: Springer.
Sandborn, P. (2004). Beyond Reactive Thinking – We Should be Developing Pro-Active Approaches to Obsolescence Management Too! *DMSMS Center of Excellence Newsletter 2*(4).
Sandborn, P. (2007). Designing for Technology Obsolescence Management. In Bayraksan, G., Lin, W., Son, Y. & Wysk, R. (Eds.), *Proceedings of the 2007 Industrial Engineering Research Conference Norcross* (pp. 1684-1689).
Saunders, G.E., (2006). *Diminishing Manufacturing Sources and Material Shortages (DMSMS) Guidebook.* Department of Defense, Office of the Under Secretary of Defense, Acquisition, Technology & Logistics. Washington, DC, USA. Retrieved May 31st, 2017 from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA482064.
SB Seating (2015). SB Seating Annual Report 2015. Retrieved April 19th, 2017 from: www.sbseating.com/storage/ma/3848bee1313d4230b4765e0a2f-67c764/3469365786454e928da53d654dcb479e/pd-f/084BB42B20EA73CE90DEA887C32F330566D91FDD/ENG_Annual%20report_2015_WEB.pdf.
Sirkin, T., & ten Houten, M. (1994). The cascade chain: a theory and tool for achieving resource sustainability with applications for product design. *Resources, Conservation and Recycling*, *10*(3), 213-276.
Slade, G. (2007). *Made to Break - Technology and Obsolescence in America*. Cambridge, MA, U.S.A.: Harvard University Press.
Sood, A., James, G. M., Tellis, G. J., & Zhu, J. (2012). Predicting the path of technological innovation: SAW vs. Moore, Bass, Gompertz, and Kryder. *Marketing Science*, *31*(6), 964-979.
Sood, A. & Tellis, G.J. (2005). Technological Evolution and Radical Innovation. *The Journal of Marketing, 69*(3), 152-168.
Stahel, W. R. (2010). *The Performance Economy* (2nd ed.), Hampshire, UK: Palgrave Macmillan Hampshire.
Stark, J. (2015). *Product Lifecycle Management (Volume 1) - 21st Century Paradigm for Product Realisation* (3rd ed.). Switzerland: Springer International Publishing.
Stout, L. (2017). *Corporations Don't Have to Maximize Profits*. Retrieved May 10th, 2017 from www.nytimes.com/roomfordebate/2015/04/16/what-are-corporations-obligations-to-shareholders/corporations-dont-have-to-maximize-profits.
Tani, T. (1999, February). Product development and recycle system for closed substance cycle society. In *Environmentally Conscious Design and Inverse Manufacturing, 1999. Proceedings. EcoDesign'99: First International Symposium On* (pp. 294-299). IEEE.
Tata (2016). Tata Consultancy Services, part of the TATA group. *Redefining Product Lifecycle Management in a Circular Economy*. Retrieved June 18th, 2017 from www.tcs.com/content/dam/tcs/pdf/Industries/manufacturing/abstract/Redefining%20Product%20Lifecycle%20Management%20in%20a%20Circular%20Economy%20-.pdf.
Taylor, M., & Taylor, A. (2012). The technology life cycle: Conceptualization and managerial implications. *International journal of production economics*, *140*(1), 541-553.
TechTarget (2017). IT asset disposition (ITAD). Retrieved April 20th, 2017 from: http://whatis.techtarget.com/definition/IT-asset-disposition-ITAD.
Tedrive (2017a). Tedrive steering at a glance. Retrieved April 22nd, 2017 from: www.td-steering.com/about-td-steering.html.
Tedrive (2017b). Milestones in our history. Retrieved april 22nd, 2017 from: www.td-steering.com/history-td-steering.html.
Tedrive (2017c). Steel housing. Retrieved April 22nd, 2017 from: www.td-steering.com/steel-Housing.html.
Terzi, S., Bouras, A., Dutta, D., Garetti, M., & Kiritsis, D. (2010). Product lifecycle management - from its history to its new role. *International Journal of Product Lifecycle Management* 4(4), 360-388.
Thierry, M., Salomon, M., Van Nunen, J. & Van Wassenhove, L. (1995). Strategic Issues in Product Recovery Management. *California Management Review 37*(2), 114-135.
Tischner, U., Schminke, E., Rubik, F., & Prösler, M. (2000). *How to do EcoDesign? A guide for environmentally and economically sound Design.* In collaboration with B. Dietz, S. Maßelter & B. Hirschl, edited by the German Federal Environmental Agency. Frankfurt am Main, Germany: Verlag form Praxis.

Tonelli, F. L., Taticchi, P. A., & Starnini Sue, E. (2009). A framework for assessment and implementation of product-service systems strategies: learning from an action research in the health-care sector. *WSEAS Transaction on Business and Economics*, *6*(7), 303-319.
Tukker, A., & Tischer, U. (Eds.) (2006). New Business for Old Europe - Product-service development, competitiveness and sustainability. Sheffield, UK: Greenleaf Publishing Ltd.
Tukker, A., Van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In Tukker, A., & Tischner, U., (Eds.), *New Business for Old Europe - Product-service development, competitiveness and sustainability*. Sheffield, UK: Greenleaf Publishing Ltd.
Vandermerwe, S., & Rada, J. (1988). Servitization of business: adding value by adding services. *European management journal*, *6*(4), 314-324.
Van Nes, N. (2003). Replacement of Durables: Influencing product life time through product design (Doctoral thesis). Erasmus University Rotterdam, Rotterdam, the Netherlands.
Van Nes, N., & Cramer, J. (2005). Influencing Product Lifetime through Product Design. *Business Strategy and the Environment 14*, 286-299.
Van Nes, N., Cramer, J., & Stevels, A. (1999). A Practical Approach to the Ecological Lifetime Optimization of Electronic Products. In *Proceedings of First International Symposium On EcoDesign '99* (pp. 108-111), Februari 1-3, 1999, Tokyo, Japan.
Van Weelden, E., Mugge, E. R., & Bakker, C. A. (2016). Paving the way towards circular consumption: exploring consumer acceptance of refurbished mobile phones in the Dutch market. *Journal of Cleaner Production, 113*, 743-754.
VFC (2016). *VF Corporation 2016 Annual Report*. Retrieved November 23rd, 2017 from https://ir.vfc.com/annual-reports
VFC (2017). Eastpak. Retrieved April 19th, 2017 from www.vfc.com/brands/outdoor-action-sports/eastpak.
Vernon, R. (1966). International investment and international trade in the product cycle. *The Quarterly Journal of Economics 80*(2), 190.
Westkämper, E., Alting, L., & Arndt, G. (2000). Life Cycle Management and Assessment: Approaches and Visions Towards Sustainable Manufacturing. *CIRP Annals - Manufacturing Technology 49*(2), 501-526.
WSWS (2017). German technology manufacturer Loewe declares bankruptcy. Retrieved April 21st, 2017: www.wsws.org/en/articles/2013/10/12/loew-o12.html.
Xing, K., Luong, L., & Abhary, K. (2005, March). A methodical planning to enhance reutilisation potential in product design. In *Asian Green Electronics, 2005. AGEC. Proceedings of 2005 International Conference on* (59-66). IEEE.
Zeithaml, V.A. (1988). Consumer Perceptions of Price, Quality and Value: A Means- End Model and Synthesis of Evidence. *Journal of Marketing, 52*, 2-22

5

6

A DESIGN METHODOLOGY FOR MANAGING OBSOLESCENCE

To what extent can some combinations of design interventions and business model types be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?

6.1 INTRODUCTION

Chapter 6 presents (the development of) a design methodology for managing obsolescence. Design for managing obsolescence is intended to enable industrial designers to tailor their product designs to circular business models for preserving product integrity. The objective of chapter 6 is to create a set of design methods in support of managing obsolescence, including an overview of which combinations of design interventions for preserving product integrity and types of circular business models for preserving product integrity can be expected to be successful when managing obsolescence. With the latter overview, chapter 6 aims to provide an answer to sub-research question E: "To what extent can some combinations of design interventions and business model types be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?"

In chapter 5, we introduced the concept of managing obsolescence as a potential business practice for circular business models for preserving product integrity to surmount the first barrier to maximizing business model circularity, i.e., a way of minimizing the unpredictability of the quantity and quality of the return flow of obsolete products.

Managing obsolescence – or the cross-disciplinary practice of *preserving product integrity by aligning value propositions and business models with product states over a product's entire lifetime, ahead of time* – requires industrial designers (and other business professionals) to carefully coordinate the potential for preserving product integrity that is to be designed into a product with what is required to ensure the realization of this potential over time. This is a new and complex challenge for which the literature on (sustainable) product design as of yet (as the concept of managing obsolescence was newly introduced in this thesis) does not provide a design methodology. When successful, however, design for managing obsolescence could help circular business models for preserving product integrity surmount the second barrier to maximizing business model circularity, i.e., optimize the alignment between actions required to achieve environmental business objectives and actions required to achieve economic business objectives in order to minimize the *"mismatch"* (p. 104) as observed by Rose (2000) (see section 5.3)

Designing for managing obsolescence consists of two parallel, iteratively interacting, but above all coordinated, processes that are of equal importance to its overall success.
Firstly, there is the process of designing a tangible product for a number of use cycles in conjunction with a predetermined sequence of interventions for preserving product integrity that have the potential to maximize business model circularity, i.e., minimize the environment load associated with the product over its entire lifetime.

Most of the existing methods for calculating the environmental load associated with (the use of) a tangible product over its entire lifetime, such as Life Cycle Analysis (LCA) (e.g. Stevels, 2007; ISO, 2006, Tischner et al., 2000) and those for calculating the business-economic implications of closed-loop recovery processes in a circular economy (e.g. Atasu et al., 2008), work on the basis of scenarios that describe what happens with a product over its entire lifetime. When offered a (number of) potentially suitable product life cycle scenario(s) as initial input and working from a particular set of assumptions, these existing methods could be used to, by way of iteration, determine the (theoretically) ideal scenario(s) for a particular type of tangible product that would allow a circular business to preserve the economic value added to its particular products to a maximum extent, thus maximizing the circularity of the business model that the product is embedded in. However, although they depend on product life cycle scenarios as input for their calculations, these existing methods cannot be used to generate the scenarios that form the bases for their calculations. In sub-section 6.3.1, we will therefore present a new design method for generating (and facilitating the initial comparison of) potential product life cycle scenarios for managing obsolescence.

Secondly, there is the design and development of a predetermined sequences of value propositions and business model instances to support these value propositions. For each new product use cycle, these value propositions and business model instances describe how a company intends to combine the tangible component of the value proposition (i.e., tangible products that are in a certain condition (e.g., new, used-as-is, refurbished or remanufactured) with an intangible component in order to generate a combination that has sufficient perceived use value to make the process economically profitable in the short and long term. The aim of this predetermined sequence of value propositions and supporting business model instances is to leverage the pristine, or provide compensation for the diminished, condition of the product, in order to help ensure that the environmentally optimal product lifetime scenarios (as established for example through an LCA) are realized as planned, i.e., to help ensure that the potential for preserving product integrity as designed into the product is fully realized and the highest possible level of business model circularity is achieved. To accurately capture and reflect the product condition and time dependent properties of these predetermined sequences of value propositions and business model instances, we will in sub-section 6.3.2 present two new design methods for generating (and facilitating the initial comparison of) these sequences of value propositions and supporting business models that are required when managing obsolescence.

Completing the design methodology for managing obsolescence, we present in section 6.4 a conceptual proposition for a new design method that is intended to provide guidance to industrial designers (and other business professionals) when working with the design methods for managing obsolescence proposed earlier, i.e., developing the lifetime scenarios and predetermined sequences of value propositions and business model instances to support these scenarios. This method is based on the answer to sub-research question E, "to what extent can some combinations of design interventions and business model types be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?", and is intended to offer an overview of which combinations of design directions for preserving product integrity and circular business model types for preserving product integrity can be expected to be successful when managing obsolescence.

Chapter 6 ends with section 6.5 discussing the findings of and presenting the conclusions for this chapter.

6.2 METHODOLOGY

Gathering Data

The results from the review of the literature from the domains of (sustainable) design and business sciences as synthesized in the previous chapters form the starting point for the development of the four design methods as presented in the current chapter. For methodology and search terms we refer to the respective methodology section (i.e., sections 2.2, 3.2, 4.2 and 5.2). At present, neither a circular economy, nor the newly proposed practice of managing obsolescence are realities. Performing longitudinal experiments to gather the requisite empirical data – if at all possible in the current linear economic context – is beyond the scope of the thesis. As such, empirical data from the practice of managing obsolescence in an absolute circular economy context is not available and so the design methods presented in this chapter (and thesis) are based on theory.

For the development of the fourth design method, intended to provide guidance to industrial designers (and other business professionals) when working with the design methods for managing obsolescence, we have revisited the literature on (sustainable) product design and PSS-based business model types with a specific focus on literature providing indications as to which design directions (for preserving product integrity) and PSS-based business models, such as the circular business models for preserving product integrity presented in section 4.6, can be expected to be more (or less) successful than others. We thus looked at literature explicitly discussing 1) combinations of design directions and PSS-based business models that can be expected to be successful, 2) factors that affect to what extent design directions for preserving product integrity can be expected to be successful, and 3) factors that affect to what extend PSS-based business models can be expected to be successful. As the literature on (sustainable) product design and PSS-based business model types proved inconclusive with regard to the extent to which particular combinations of design directions and PSS-based business model types can be expected to be successful – and more (or less) successful than others – on the bases of these factors, we expanded our search. In addition to the literature on (sustainable) product design and PSS-based business model types, we looked at literature from the business sciences discussing in more detail the above factors that affect the extent to which combinations of design directions and PSS-based business models can be expected to be successful.

The review of the literature is based on the procedures described by Hagen-Zanker and Mallet (2013) as discussed in section 1.5 Research Design and draws from scientific publications in the fields of (sustainable) product design and the business sciences. We complied the initial body of literature, limited to documentary sources in the English, Dutch or German language but without limits to publication date, from the search results returned by Google Scholar, for (combinations of) search terms related to PSSs and design interventions. The initial list of search terms consists of (combinations of): (product) design, design for product-service systems, PSS* and product-service system*. Using snowballing, we added new keywords that emerged, such as industry life cycle (stage*), product life cycle (stage*), technology life cycle (stage*), introduction, growth, maturity and decline to the initial set. The results of the searches were scan-read to determine, based on the author's 20 years of experience in the fields of commercial industrial design and sustainable design and erring on the side of caution, whether they pertained to product design, product design for extended lifetimes, circular economy, sustainability and business in a manner that was potentially relevant to the topic of the research. Clearly irrelevant results, for example highly technical econometric or computing related papers, were discarded before storing the results in a software-based retrieval system and assigning (additional) keywords to them for later reference.

In total, we studied over 150 articles in detail in order to gain a deeper understanding of the matter at hand, identify the *seed literature* (works of research on the topic considered as fundamental in the specific field) and to detect similarities, discrepancies, inconsistencies, and/or contradictions (Hart 2011).

Processing and Analysing Data
In developing and populating the conceptual proposition of the fourth design method for managing obsolescence, we first used the data from the literature review to assess to what extent – and for what reasons – some combinations of design interventions and PSS-based business model types could be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others. For lack of data on circular PSS-based business model types, we have worked under the assumption that these findings would hold true for circular PSS-based business model types as well.

Based on the findings from the expanded review of the literature mentioned above and the more than 20 years of industry experience of the author, inferences were next made as to what extent particular combinations of design directions and circular business model types could be expected to be successful under certain conditions. Lastly, we created a visual overview that employed the three-dimensional space for preserving product integrity (see section 3.7 and figure 3.7.1) to represent the combinations of the design directions that, according to our inferences, could be expected to be successful when applied in conjunction with particular circular business model types and conditions. Because the overview that constitutes the fourth design method was made on the basis of incomplete and non-validated information, we present it as a conceptual proposition only.

Because 1) chapter 3 showed that many of the individual design strategies for preserving product integrity are connected and supported by the same design principles 2) the amount of (empirical) research that presently is available on combinations of design interventions, PSS-based business models and industry life cycle stages is limited (Antikainen, Lammi, Paloheimo, Rüppel & Valkokari, 2015; Reim et al., 2015) and 3) the research presented in this thesis is at type (and not instance) level, we present our findings with regard to design interventions at the level of the three main design directions (i.e., resisting, postponing or reversing obsolescence) instead of at the level of the eight individual design strategies.

6.3 Three Design Methods for Managing Obsolescence: Obsolescence Profile, Longitudinal Value Proposition and Longitudinal Business Model

As mentioned in the introduction, there are many methods available in the literature that, although not all developed specifically for use in the absolute context of a circular economy, can be used to calculate the environmental effects over the entire lifetime of a product in a circular economy. The literature also contains tools and methods that could be used for assessing the business-economic aspects of closed-loop recovery processes in a circular economy. Both categories of tools play an important part in managing obsolescence. However, although these methods can be used to quantitatively capture and compare the environmental and business-economic implications of different product lifetime scenarios, they are not suited to generate the product life cycle scenarios that are the object of their calculations. These qualitative tools and methods furthermore require elaborate modelling, are complex and time consuming and are not suited for use by non-specialists, such as industrial designers (and other business professionals). Because of their time-consuming complexity, the primary use of these tools and methods in the context of managing obsolescence lies in assessing and tweaking either the environmental or the business-economic aspects of scenarios (for managing obsolescence) that are fed into them as input. They were never intended – and therefore are not suited – for use as iterative and designerly methods for generating product life cycle scenarios, such as those for managing obsolescence that simultaneously need to take into account the environmental and business-economic effects of interventions for preserving product integrity over an entire product lifecycle.

In absence of such generative methods for product life cycle scenarios for managing obsolescence in the literature, we present in this section three, complementary, methods for generating product life cycle scenarios for managing obsolescence intended for use by industrial product designers (in close cooperation with professionals from other business functions) as part of the larger product innovation process (see Appendix A: The Product Innovation Process) in a circular economy. These new methods are intended to assist industrial designers in generating and comparing a number of alternative product designs and business concepts for managing obsolescence, but can, however, form the bases for quantitative environmental and economic analysis later on. These new methods are built on and around three new concepts, i.e., *obsolescence profile*, *longitudinal value proposition* and *longitudinal business model*, that are intended to contribute to *"a representational vocabulary for a shared domain of discourse"* (Gruber, 1993, p. 199) to industrial designers and business professionals for discussing and planning the management of obsolescence over a product's entire lifecycle. These three methods are intended to be used together in a coordinated and iterative manner to help industrial designers (and other business professionals) with generating potential scenarios for managing obsolescence and thinking through and comparing their implications.

6.3.1 Obsolescence Profile: Concept and Design Method

The first new concept and design method we introduce here is that of (making) a conceptual representation of the entire life cycle of a product, in which the moments in time when, and the ways in which, a product should become obsolete and the interventions by which obsolescence is postponed and/or reversed (e.g. product lifetime is extended) are defined. For the resulting sequence of use cycles including prevention, onset and reversal of obsolescence events we propose the term *obsolescence profile*, that we define as follows:

An *obsolescence profile* is a description of the predetermined sequence, covering the entire lifetime of a product, that lists the use cycle(s) and point(s) in time when, and the way(s) in which, a product will be prevented from becoming obsolete and/or will become obsolete and subsequently will be recovered'.

A smartphone will be used as an example to illustrate the concept and a potential obsolescence profile for a smartphone, i.e., a durable consumer product in a circular economy, is presented below (see also figure 6.3.1):

Initial release for first use cycle after (re)manufacturing/Obsolescence (induced) after 12 months/Recontextualizing 12 days/Release for second use cycle after recovery/Obsolescence (induced) after 18 months/ Refurbishing 20 days/ Release for third use cycle/Obsolescence (induced) after 24 months/End of product lifetime/Transfer to recovery at semi-finished

6

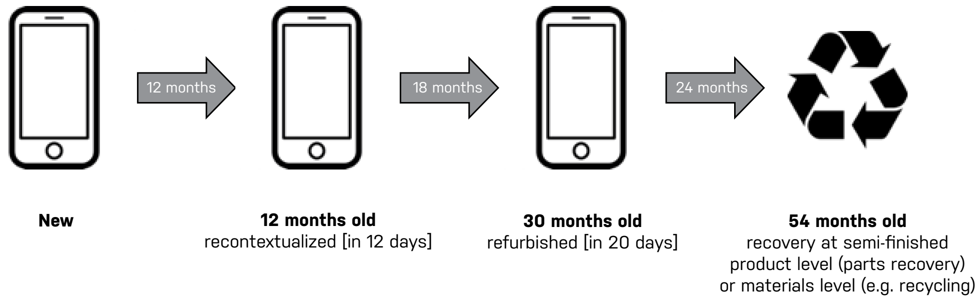


Figure 6.3.1: A graphical representation of an obsolescence profile for a smart phone.

product level (parts recovery) or materials level (e.g. recycling)/ Total number of use cycles: 3, total product lifecycle 54 months, total time as presource for recovery at end-product level: 32 days.

In line with what can be seen from the smartphone example above, every obsolescence profile starts with release of the tangible product for initial use after (re)manufacturing and ends with recovery at semi-finished product or material level. At the beginning of each obsolescence profile, product integrity is 1 (or 100%). An obsolescence profile always ends with a recovery intervention that reduces product integrity to 0 (or 0%). Note that the concept of obsolescence profile captures the items (d) to (h) on the list of items that need to be accurately assessed for successful management of obsolescence as presented earlier in section 5.6.

6.3.2 Longitudinal Value Proposition: Concept and Design Method

The second new concept and design method we want to introduce concerns (the creation of) the value proposition(s) that are built around recovered presources at each moment along the obsolescence profile where recovered presources are reintroduced onto the market.

In a linear economy, the majority of products are traded through a single transaction that involves the transfer of ownership rights (Malone et al., 2006) and in which economic value is captured (e.g. perceived use value is (partially) turned into exchange value (Bowman & Ambrosini, 2000) in the instant of the transaction (Malone et al., 2006, Bowman & Ambrosini, 2000, Herman, 1981). The value proposition associated with a product, described by Osterwalder and Pigneur (2010) as the aggregation of features and benefits that create value for a specific customer segment, in the above scenario is created with a focus on that single (moment of) transaction, as in a linear economy what happens with the item after the moment of sale - or how long it will last its new owner - is, with the exception of brand reputation considerations and legal requirements (e.g. product liability, warranty and environmental regulations), of little commercial interest to the seller and largely outside his span of control (Erler & Rieger, 2016; Malone et al., 2006).

In a circular economy, however, resources are required to be economically accounted for at all times, for as soon as they disappear from the economic loop they are lost to the circular economic system and become leakage. In an economic system that preserves the economic and environmental value of materials by keeping them in the economic system for as long as possible, preferably by lengthening the useful lifetimes of products formed from them and, when lifetime extension at product level is no longer possible for environmental

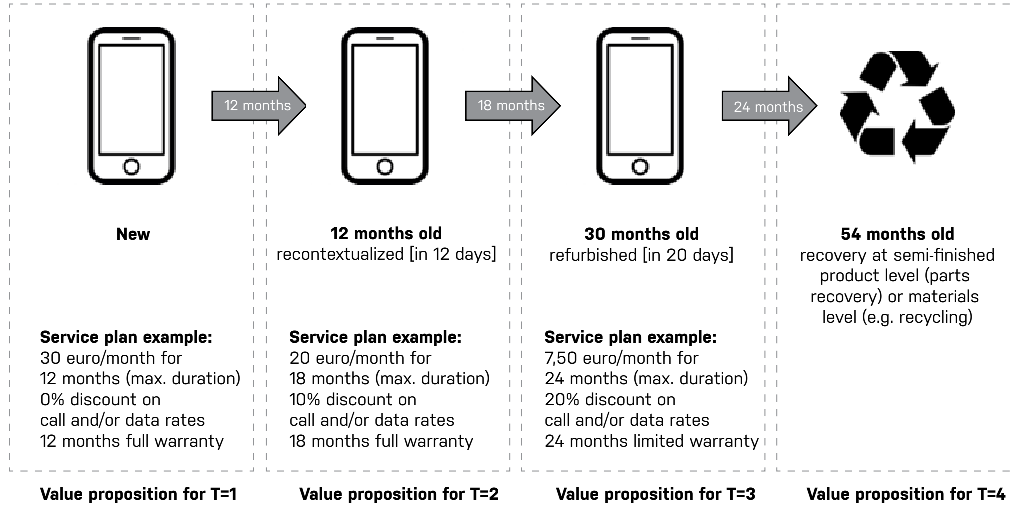


Figure 6.3.2: A graphical representation of the different value propositions for the different use cycles of an obsolescence profile for a smart phone.

or economic reasons, by looping products back into the manufacturing process so their constituent materials can be reused, it is therefore likely that different types of rights to (new or recovered) products and presources will be traded a number of times in succession as they go through a number of use cycles. In a circular economy, virtually every product will therefore, over its total lifetime, be embedded in a number of value propositions that change along the obsolescence profile, e.g. over the total lifetime, of the product.

For example, whereas a new smartphone can be offered as part of a premium priced service plan, a refurbished phone would most likely require a service plan with discounted rates to result in an attractive and viable value proposition (see figure 6.3.2).

The existing value proposition concept, however, is commonly understood to represent a single aggregation of features and benefits for a specific customer segment associated with a product (Osterwalder & Pigneur, 2010) (see Appendix B: The Business Model and Related Concepts). We therefore propose a new type of value proposition that consist of the predetermined set of the various time and tangible product state dependent value propositions that are required along a product's obsolescence profile (i.e., for all use cycles during the entire product lifetime) in support of managing obsolescence. We propose the term *longitudinal value proposition* for this new type of value proposition that, building on the description of the value proposition concept by Osterwalder and Pigneur (2010), we define here as follows:

A *longitudinal value proposition* is the predetermined set and sequence of the aggregations of features and benefits associated with a product that create value for a specific customer segment along the obsolescence profile of that product.

The adjective longitudinal is selected here as under scientific conventions it is known and understood to mean "over an extended period of time".

The longitudinal value proposition describes the predetermined set of value propositions as required over a product's entire lifetime, i.e., along its obsolescence profile, in which changes in the properties of the tangible product along the obsolescence profile (i.e., as a result of interventions for preserving product integrity) are leveraged – or compensated for – by intangible aspects of the overall value proposition, such as changes in pricing and/or service levels. The longitudinal value proposition built around a particular product, includes predetermined, time and tangible product state dependent, elements such as use cycle(s), price point(s), (additional) services and (extended) warranties, and is intended to ensure that sufficient perceived use value is offered for each use cycle to prevent the perceived use value associated with the tangible product from falling below the level that would result in the occurrence of (premature) obsolescence events that are not part of the planned obsolescence profile. The newly proposed concept and design method of (developing) a longitudinal value proposition complements the design method of developing an obsolescence profile as it stresses that a specific value proposition is required for each specific transition along a product's obsolescence profile between product and presource (and vice versa) and offers a method for helping develop and describe these value propositions in advance. As such, it provides support for the iterative process of determining which interventions for preserving product integrity should appear at what time from an environmental and economic perspective, i.e., what the obsolescence profile should (ideally) look like and could provide guidance when the need should arise to choose between multiple, environmentally equal, obsolescence profiles for a product, as these profiles might not be equal from a business-economic point of view.

Note that the concept of obsolescence profile captures the items (a) to (c) on the list of items that need to be accurately assessed for successful management of obsolescence as presented earlier in section 5.6.

6.3.3 Longitudinal Business Model: Concept and Design Method

The third new concept and design method we introduce here is a logical consequence of the introduction of both the obsolescence profile and the longitudinal value proposition and concerns the support structure(s), i.e., the business model instance(s) for the longitudinal value proposition along the obsolescence profile. If the value proposition, i.e., the combination of tangible product component and intangible service component, changes along the obsolescence profile of a product, it is likely that the business model as a whole also has to also change along the obsolescence profile of a product, as it is the construct that supports and brings together the tangible and intangible components of the value proposition. The interviews with BMA Ergonomics in sub-section 5.5.4 for example showed that BMA Ergonomics employs both different pricing and channels for their new and for their refurbished office chairs. Key partners and/or resources required to manufacture or refurbish a smartphone for example are likely to be different from those required to recover resources from obsolete smartphones at a semi-finished product or material level. The customer segment for new smartphones is likely to be different from the customer segment for refurbished smartphones or that for the materials recovered from obsolete smartphones. The same can be said for all elements that together make up the business model, whether these elements are represented in the form of nine business model building blocks as proposed by Osterwalder and Pigneur (2010) or as the components and partial models of the integrated business model as proposed by (Wirtz, Pistoia et al., 2016) (see Appendix B: The Business Model Concept and Related Concepts). Additionally, it could be possible that the longitudinal value proposition requires the applied type of circular business model for preserving product integrity to shift from one type, e.g. Access model, to another, e.g. Classic Long Life, along the obsolescence profile and product lifecycle.

The literature is clear that the development of a business model is not a one-time event that is to be done only once at the start of a business (e.g., Saxena et al., 2017; Wirtz; Pistoia et al., 2016; Boons & Lüdeke-Freund, 2013; Casadesus-Masanell & Ricart, 2010). Business models can be expected to change over time (see Appendix B.2.1: The Business Model Concept). This normal process of business model change, however, can be described as the ongoing and iterative process of continuous adjustments to and maintenance of a business model over time (Saxena et al., 2017; Wirtz, Pistoia et al., 2016; Boons & Lüdeke-Freund, 2013; Casadesus-Masanell & Ricart, 2010)

In addition to the ongoing and iterative process of continuous monitoring, adjustment and maintenance that is normal for every business model, however, the support of a longitudinal value proposition requires a series (*parallel and in sequence*) of different business models for a particular type of product over time that is predetermined and known in advance for the entire lifecycle of (the instances of) a particular product type, as in some instances the longitudinal value proposition needs different business models to support it over time (e.g., different channels, different key partners).

We argue therefore that the concept (and development process) of a predetermined set and sequence of business models required for supporting a longitudinal value proposition is therefore markedly different from the concept of an existing business model that slowly changes and evolves over time. To distinguish business models that have these unique and time dependent properties in support of longitudinal value propositions from more conventional business models, we propose a new term, *longitudinal business model*, for this new type of business model. Building and expanding on the existing business model concept definition as proposed by Osterwalder and Pigneur (2010), we define the concept of a longitudinal business model as follows:

A *longitudinal business model* is the predetermined set and sequence of rationales of how an organisation creates, delivers and captures value that is required to support the longitudinal value proposition built around a product along the obsolescence profile of that product.

The longitudinal business model that (an instance of) a particular type of product is embedded in over its lifecycle, includes predetermined, time and product state dependent elements such as (longitudinal) value proposition, customer segment(s), key partners and resources, and can help to offset product state related changes in perceived value, thereby offering a means to controlling perceived value over time in the management of obsolescence.

When developing dynamic business models for managing obsolescence, the business model canvas (Osterwalder & Pigneur, 2010), that is presently much used in education and industry to help develop specific business model instances (see Appendix B.2.2: Business Model Ontology) can still be used as a tool for graphical representation in development sessions for longitudinal business models. Each sequential business model canvas along the obsolescence profile or lifecycle of the product should, however, be regarded as one of a series of still frames from a movie that changes over time rather than as a single photograph, as visualized in figure 6.3.3.

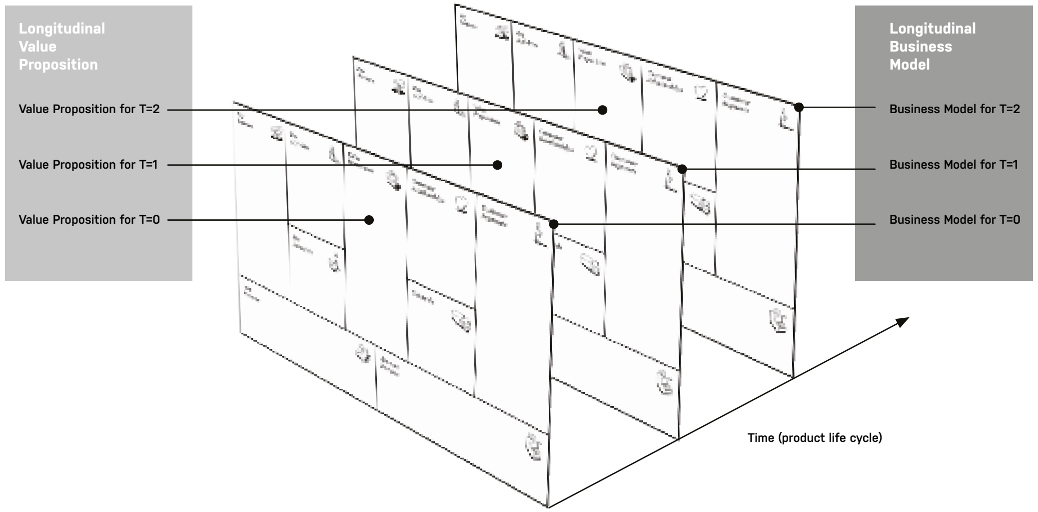


Figure 6.3.3: The sequential use of the Business Models Canvas (Osterwalder & Pigneur, 2010) to graphically represent the concept of a longitudinal business model and a longitudinal value proposition, whereby each individual Business Model Canvas should be regarded as one frame from a series of still frames from a movie that changes over time rather than as a single photograph.

6.4 A HEURISTIC FRAMEWORK FOR DESIGN FOR MANAGING OBSOLESCENCE

The Need for a Design Method That Can Provide Guidance when Designing for Managing Obsolescence

Design for managing obsolescence, i.e., the creation of obsolescence profiles, longitudinal value propositions and longitudinal business models and taking these as input for the design of tangible products, requires industrial designers (and other business professionals) to make complex and often interrelated decisions, many of which can be based only on assumptions with regard to future developments. Although this, in principle, is the same in more conventional product innovation processes, it may be clear from the preceding chapters that the developments that have to be taken into account when designing for managing obsolescence differ from those that are performed in the context of business models of the Sell More, Sell Faster type, in that they tend to stretch further into the future, and more often than not involve multiple use cycles, potentially by different users and in the context of different business model types. A design that facilitates, for instance, maintenance or repair for one actor can turn out to be impossible to maintain or repair for the other. This is a complicating factor. Product designers aiming to design for maintenance and/or repair need to ask the question: Who will perform the maintenance or repair and where? Is it a layman user at home, a professional in the workshop, or perhaps a robot at the manufacturer? This involves taking into account factors like a product's particular business context and the business model it is embedded in. This may, for instance, determine to what extent a manufacturer chooses to limit or allow access to the workings and innards of its products (see section 3.8). It follows that many design interventions for preserving product integrity need to be applied in conjunction with business models that allow the (repeated) capture of economic value over time. For example, in order to make a product that was designed for remanufacturing really work, obsolete products need to be consistently returned to the original equipment manufacturer (or a licenced third party) to be remanufactured (see sub-section 2.5.3 and section 3.8). This requires arrangements for reverse logistics and a transactional model that allows the (re) manufacturers to retain economic control of their product over time (see sub-sections 4.6.2, 4.6.3 and 5.3.2).

On top of the normal challenges posed by the product innovation processes as they are performed in the context of a linear economy, design for managing obsolescence thus provides at least two additional challenges that are new to industrial designers: To design in the *temporal* dimension as well as in the spatial dimension, and to consider and decide on design interventions for preserving product integrity in conjunction with business model types.

To help industrial designers meet these additional challenges, the Inertia Principle (see section 2.3) can serve as one design method in the form of a guiding principle for helping industrial designers select interventions for preserving product integrity – and establishing the order in which they should be applied – that would be preferable from an environmental point of view. Other, quantitative methods, like for example LCA, can help industrial designers gain deeper insights into the environmental consequences of their design interventions, and help them to avoid scenarios in which the environmental impacts from the prolonged use of a product become larger than the embedded impacts of a more efficient replacement product (Bakker, Wang et al., 2014). Although necessary and valuable, the methods mentioned above are not sufficient, for when designing for managing obsolescence, it is essential that the types of interventions for preserving product integrity – and the order in which they should be applied – are considered not only from an environmental perspective but from a business-economic point of view (e.g. in conjunction with business model types) as well. As was discussed earlier in section 1.1., however, the field of eco-design has framed product lifetime extension mainly from a resource efficiency perspective (De Pauw, 2015; Bjørn & Hauschild, 2012) and largely ignored the business implications ushered in by the circular economy concept. As a consequence, a design method to provide guidance to industrial designers (and other business professionals) in selecting (design) interventions in conjunction with circular business model types for preserving product integrity, with the aim of leveraging the design of tangible products and their business-economic context in order to systematically maximize business model circularity, has so far not been developed.

In the remainder of this section, we will therefore present (the development of) such a design method.

6.4.1 Successful Combinations of Design Directions and Circular Business Model Types for Preserving Product Integrity: A Review of the Literature

In this sub-section, we will begin the development by reviewing the literature on (sustainable) product design and PSS-based business model types in order to find out to what extent it contains information on what combinations of design directions for preserving product integrity and circular business model types for preserving product integrity are successful, and whether some combinations are more successful than others.

Literature on The Relationship between Design Directions for Preserving Product Integrity and PSS-based Business Model Types

Only a limited number of publications distinguishes between different types of PSS-based business models when discussing design directions in relation to PSS-based business model types (e.g., Bocken et al., 2016; Reim et al., 2015, Bakker, Den Hollander et al., 2014). The findings from these publications are now discussed below.

There is general agreement in the literature that product-oriented PSS-based business model types are mostly oriented toward servicing the tangible product (Reim et al., 2015; Tukker 2015; Gaiardelli et al., 2014; Tukker et al., 2006). This focus on servicing the tangible product requires the tangible products for this type of PSS-based business model to be designed in such a way that they are easy to maintain in support of maintenance contracts and/or that their parts are selected or designed in such a way that they can easily be reused to support take-back agreements that are often an important part of product-oriented PSS-based business model types (Reim et al., 2015; Williams, 2007; Sundin & Bras, 2005). With regard to take-back agreements, Sundin and Bras (2005) stressed that in order for them to work well in a business-to-consumer setting, it is essential that the tangible products, such as household appliances, are easy to remanufacture. As the number of users is generally rather high in product-oriented PSS-based business model types, *"no major changes are made to the products and services"* (Reim et al., 2015, p. 71) nor are required (Reim et al., 2015; Azarenko, Roy, Shehab & Tiwari, 2009) in order to serve the specific needs of individual customers.

Bocken et al. (2016) reiterated that in product-oriented PSS-based business models *"value creation and delivery focuses on durable product design and high customer service levels (e.g. repair, maintenance)"* (p. 314). As such, Bocken et al. (2016) asserted, in line with Bakker, Den Hollander et al. (2014), that a product-oriented PSS-based business model type is *"supported by design for durability and repair"* (Bocken et al., 2016, p. 314).

In use-oriented PSS-based business model types, where the provider is responsible for the availability and usability of the tangible product (Reim et al., 2015; Tukker 2015; Gaiardelli et al., 2014; Tukker et al., 2006), ease of maintenance and repair of the tangible product is even more important than it is in product-oriented PSS-based business model types (Reim et al., 2015; Azarenko et al., 2009). In addition, Reim et al. (2015) found that the aspect of physical durability of the tangible product gains in importance too in use-oriented business model types, as tangible products are often meant to be used more frequently in these business model types (Evans et al., 2007). In use-oriented PSS-based business model types, the ownership of the tangible product remains with the (same) provider. The users of the tangible product, however, are likely to change over the lifetime of the product. As such, *"ease of upgrading and remanufacturing"* (Reim et al., p. 71) works to the advantage of both the PSS provider and the users of the tangible product (Reim et al., 2015; Kuo, 2011; Aurich, Fuchs & Wagenknecht, 2006; Mont et al., 2006) as it enables the product to meet the needs of different users and can *"enable a longer lifetime for the product"* (Reim et al., p. 71). As *"ensuring a certain level of availability"* (Reim et al., 2015, p. 71) is essential to use-oriented PSS-based business model types, it is *"especially important ... that products and services are designed to reliably meet the contracted availability"* (Reim et al., 2015, p. 71). Similar to product-oriented PSS-based business model types, the numbers of users in use-oriented PSS-based business models can often be quite high, so customisation of products and/or services is generally limited (Reim et al., 2015). When use-oriented services are offered to large (often business-to-business) customers, however, such as in pooling and sharing scenario's, products sometimes need (and are) adapted to meet the special needs of these customers (Reim et al., 2015).

In result-oriented PSS-based business model types, the main purpose of the product-service combination is to deliver to the customer the result that was agreed upon (Reim et al., 2015; Tukker 2015; Gaiardelli et al., 2014; Tukker et al., 2006). In these types of business models, *"the opportunities for* [design interventions for enhancing] *functionality are significant ... because any specific product or service can be combined to design a PSS offering that would meet the agreed upon requirements or results"* (Reim et al., 2015, p. 71). Because, similar to use-oriented PSS-based business model types, the provider retains ownership of the tangible product and uses the tangible object as a means of production (Reim et al., 2015; Tukker 2015; Gaiardelli et al., 2014; Tukker et al., 2006), *"ease of upgrading and remanufacturing"* (Reim et al., 2015, p. 71), durability, reliability and repairability of the tangible product are of prime importance (Reim et al., 2015). In addition, flexibility becomes essential, because different customers may have different operational processes and requirements that need to be taken into account (Reim et al., 2015; Ulaga & Reinartz, 2011; Meier et al., 2010; Azarenko et al., 2009;). As such, result-oriented PSS-based business model types *"will always require a higher degree of customization"* (Reim et al., 2015, p. 72), than product-oriented and use-oriented PSS-based business model types. A potential advantage of this need to adapt the design of the product and service to the special needs of the customer is that it can lead to innovations that could benefit the user, the provider and potentially even our wider society (Reim et al., 2015; Tukker, 2004).

The intensified use of the tangible products in both the use-oriented and result-oriented PSS-based business model types makes it less likely that products become obsolete *before their time*, i.e., earlier then was planned in the obsolescence profile, as the total useful lifetime of a product is compressed in a shorter amount of calendar time (Reim et al., 2015).

As may be clear from the above, there is agreement in the current literature on the relationship between design directions (for preserving product integrity) and PSS-based business model types that all three of the main design directions for preserving product integrity (i.e., resisting, postponing and reversing obsolescence) can be expected to be successful to a certain extent when used in conjunction with PSS-based business model types. The literature furthermore indicates that, because of intensified use, design for preserving integrity is even more important for use-oriented and result-oriented PSS-based business model types than it is for product-oriented PSS-based business model types (Reim et al., 2015). Other than this, however, the literature (even the literature that distinguishes between the three PSS-based business model types (e.g., Bocken et al., 2016; Reim et al.,2015)) provides little information as to what particular combinations of design directions and PSS-based business model types are more (or less) successful than others.

6

Literature on the Relationship between Design Directions for Preserving Product Integrity and Life Cycle Stages

In addition to what was discussed above, the literature contains indications that the extent to which design directions for preserving product integrity are successful will differ depending on life cycle stages pertaining to the particular tangible product

For example, when developing *"ELDA"* (Rose & Ishii, 1999, p. 2) (the ELDA acronym stands for End-of-Life Design Advisor, a predictive Design for Environment tool to assist industrial designers in their design decision with regard to end-of-life strategies), Rose and Ishii (1999) found that when industrial designers had to design a new product for a particular product category (e.g., television sets, smart phones, cookware etc.) - both the *"design cycle"* (p. 8) and the *"technology cycle"* (p. 8) for that particular product affected which end-of-life design strategies were more, less, or even not appropriate for that particular product. Rose & Ishii (1999) defined *"design cycle"* (p. 8) as *"the length of time between successive generations of a product or the frequency that a design team redesigns the product or designs a new product that makes the original product obsolete"* (p. 8) and defined *"technology cycle"* (p. 8) as *"the length of time that the product will be on the leading edge of technology before new technology makes the original product obsolete or less desirable"* (p. 8).

Both design cycles and technology cycles can differ greatly between different product categories or industries (Rose, 2000). For example, a typical design cycle for cars is 2-4 years, whereas a typical design cycle for inkjet printers is 1 year (Rose, 2000). The typical technology cycle of cars is 10-20 years, but for computers it is 6 months to 1 year (Rose, 2000).

A similar approach can be found in the domain of life cycle engineering where Xing, Luong and Abhary (2005) presented a two-stage design methodology for products, intended to systematically *"enhance reutilisation potential* [of components] *in product design"* (p. 59). The aim of the first stage was *"to identify the suitable reutilisation strategy for the product and the corresponding fate of its components"* (Xing et al., 2005, p. 60). Acknowledging that *"the destiny of a component is influenced by its time-dependent conditions, physical as well as functional"* (p. 60), Xing et al. (2005) proposed the *"design cycle of a component"* (p. 61) and the *"technology cycle of a component"* (p. 61) as two of the inputs for their formula for *"component reusability"* (p. 59). As the formula was developed expressly to determine whether a component could be successfully used in combination with a product that was designed for reuse, remanufacture or recycling, or that either the design strategy or the component (or both) had to be changed, this is a clear indication that Xing et al. (2005) considered (the appropriateness of) design strategies to also be design cycle and technology life cycle dependent.

In the literature of industrial product design, Eger and Drukker (2012, 2010) asserted that products in the early stages of the *"economic product life cycle"* (Eger &Drukker, 2010, p. 47), e.g., introduction or growth, benefit most from design interventions aimed at *"improved functionality, reliability, ergonomics, and safety"* (Eger & Drukker, 2010, p. 50), whereas products in the later stages of the economic life curve, e.g. maturity and decline, benefit most from design interventions aimed at improving *"product aesthetics"* (Eger & Drukker, 2010, p. 50), enabling *"customization and co-creation"* (Eger &Drukker, 2010, p. 51) and *"increasing emotional benefits"* (Eger & Drukker, 2010, p. 52). They furthermore reported that when the developments get to a point where ethical concerns become part of these emotional benefits, *"the ethical behaviour of the producing company does to some extent influence consumers' choices"* (Eger & Drukker, 2010, p. 52). According to Eger and Drukker (2010), it is at these later stages that companies *"can, for instance, be successful with products that become more attractive with use ("positive aging")"* (Eger &Drukker, 2010, p. 52), i.e., products that have been designed for emotional and physical durability.

The literature discussed above indicates that the extent to which a particular design strategy or direction is successful depends on various life cycle stages (e.g. design cycle, technology cycle, economic product cycle) as they pertain to particular products. As both design and technology cycles differ substantially between products (Rose, 2000), the findings by Xing et al. (2005) and Rose & Ishii (1990) imply that the extent to which end-of-life design strategies are more or less appropriate to a particular product also depends on the product type.

As with the literature on the relationship between design directions and PSS-based business model types discussed earlier, much of the current literature documenting the relationship between design directions (for preserving product integrity) and life cycle stages does so in a general manner, i.e., it indicates a relationship between the two but does not mention which design directions or strategies for preserving product integrity are more (or less) successful when applied in a particular life cycle stage (e.g., technological or economic) as it pertains to a product (e.g., Rose & Ishii, 1992; Xing et al., 2005). Only some of the literature, e.g. Eger and Drukker (2012, 2010), offers a somewhat more specific connection between design directions (for preserving product integrity) and life cycle stages.
It is difficult, however, to bring the above life cycle stage related findings together in a unified manner, as they 1) refer to time-dependent cycles surrounding a product, i.e., design cycle, technology cycle and economic product life cycle, that differ both in level of aggregation (e.g., product model or product category) and life cycle type (e.g., technological or economic) and 2) the different aggregation levels are not explicitly stated.

Literature on the Relationship between PSS-based Business Model and Product Types
The literature on PSS-based business model types presents a number of factors that affect customer acceptance of PSS-based business models and thus to what extent these PSS-business models will be successful (see table 6.4.1).

In addition to (and partly as a result of) the factors shown in table 6.4.1, Antikainen et al. (2015) found that PSS-based business model types are not equally suited for products from different categories or industries. Antikainen et al.'s (2015) reported, for example, that the vast majority of respondents from their research sample would be inclined to consider *"renting instead of owning"* (Antikainen et al., 2015, p. 8) for products like cars (187 respondents out of 240) and hobby equipment (210 respondents out of 240), whereas less than half of the customers would be inclined to do so for products like washing machines (107 respondents out of 240), and even smaller number would consider renting clothing (35 respondents out of 240) (Antikainen et al., 2015).

With regard to the reasons for this resistance to PSS-based business model types for particular product types, the findings of Antikainen et al. (2015) corroborated those of Armstrong et al. (2015), who found that *"negative perceptions were most driven by a lack of trust in the service provider and perceived barriers to ease of use, such as a lack of accessibility to the product or the technical requirements that may be commanded"* (p. 1).

Antikainen et al. (2015) furthermore found that

> business models that do not remind consumers of existing models are likely to experience resistance; it is easier to gain acceptance of a new practice when it closely resembles other practices that are already common. A good example would be Airbnb – consumers are already used to booking hotels online and so going to Airbnb entails a very similar booking practice to ordinary hotel booking (p. 4).

Although the literature (e.g. De los Rios & Charnley, 2016) suggests that most of the factors that affect the acceptance and likelihood of success of PSS-based business model types

6

Factors influencing customer acceptance of PSS-based business models	
Category	*Factor*
PRICE	Perceived fixed and variable costs, insight in total life-cycle costs.
	Price of products, costly most successful.
PRODUCT/SERVICE	Perceived relative advantages compared to alternatives
	Availability wherever and whenever needed, convenience.
	Transaction costs (time and money).
	Quality of the PSS, reliability.
CONSUMER	Habits as an obstacle to acceptance
	Issue of ownership.
	Environmental attitudes, may have relatively little importance.
RELATIONSHIP WITH COMPANY	Reputation, image.
	Uncertainties, risks, costs and responsibility.
	Communication between supplier and consumer

Table 6.4.1: Instance level factors influencing customer acceptance of PSS-based business models (adapted from Antikainen et al., 2015)

mentioned above could be influenced in one way or another by design interventions for preserving product integrity, it may be clear that many of them (e.g., "perceived relative advantages compared to alternative", "quality of PSS, reliability" and "reputation, image") can only be considered at the instance level (see chapter 4 and Appendix B: The Business Model and Related Concepts) of a particular circular business model for preserving product integrity.

As the thesis considers business models at the type level, we deem those factors that can only be considered at instance level to lie outside the scope of the current thesis and as such we will not discuss them further here. However, we would like to emphasize that these instance level factors cannot be ignored and must be taken into consideration by industrial designers when designing specific products tailored to managing obsolescence in the context of a particular circular business model for preserving product integrity in a circular economy.

Literature on the Relationship between PSS-based Business Model Types and Life Cycle Stages

According to Tukker et al. (2006), the conditions at the start of an *"industry lifecycle"* (p. 48) (i.e., introduction and growth stages, see Appendix E: The Product Life Cycle and Related Concepts) are such that the use of a PSS-based business model type for products introduced at these stages *"can still be useful, but is a secondary issue"* (p. 51). Matters are completely different, however, for products that are introduced in the maturity and decline stages of the industry lifecycle (Tukker et al., 2006). In these stages *"using a PSS [based] business model can be one of the strategies for creating new sources of added value: for example, because of its potential for customization and close client relationships"* (Tukker et al., 2006, p. 50). The business-economic potential of product-service based business model types in the later stages of the industry life cycle is reiterated by several other authors in the literature (e.g., Cusumano et al., 2015, Suarez, Cusumano & Kahl, 2013; Neely, 2009; Fang, Palmatier & Steenkamp, 2008). Tukker et al. (2006), however, did not differentiate between types of PSS-based business model based on the industry life cycle stage of the tangible product component of the product-service based value proposition.

Cusumano et al. (2015) addressed types of product-related services in conjunction with industry life cycle stages, arguing that *"the differences in these industry phases encourage the development of certain kinds of services over others"* (p. 564). Cusumano et al. (2015) identified *"three categories of product related services from a product firm – smoothing and adapting services, which complement* [the sale of ownership rights to] *products, and substitution services, which enable customers to pay for the use of a product without buying the product itself"* (p. 559). Cusumano et al. (2015) focused on *"product-related services"* (p. 563) offered by *"product makers"* (p. 563). However, when viewed in light of the IPS (integrated Product Services) business model typology as presented by Park et al. (2012), the descriptions of product-service combinations offered by Cusumano et al. (2015) make clear that their research also included product-service offerings that do not qualify as PSSs according to the definition adopted for this thesis (see sections 4.5 and 4.6) and are not necessarily aimed at preserving product integrity. Cusumano et al. (2015) furthermore used a three-way classification of industry lifecycle stages, i.e., the *"Ferment"* (p. 564), *"Transition"* (p. 564) and *"Mature"* (p. 564) stage, that diverges from the four-way classification of industry life cycle stages that was by Tukker et al. (2006).

Although these differences limit the extent to which the more specific findings can be transferred to the individual circular business model types for preserving product integrity and industry life cycle stages, we consider Cusumano et al.'s (2015) more general insights with regard to the use of services in light of changes in manufacturer and customer uncertainty over the course of the industry life cycle useful.

According to Gebauer et al. (2015), and in line with Tukker et al. (2006), *"the general argument* [in the current, maturity stage focused, empirical work on PSSs] *is that companies should shift from product-oriented to user-oriented and, finally, performance oriented PSS when they reach the maturity phase"* (p. 44). Cusumano et al. (2015), however, asserted that the business-economic potential of product-service based business model types is more than *"secondary"* (Tukker et al., 2006, p. 50) in industry life cycle stages other than the maturity stage:

> services are not simply complements to products and only important when products are mature. They can be much more for the product firm. Services can help ignite a new market during the era of ferment, accelerate industry shakeout or the establishment of a dominant design, improve the financial performance of firms competing in mature industries with declining product businesses, or even create a market disruption. Services may also be effective substitutes for product purchases under the right conditions (p. 572)

Cusumano et al. (2015) argued that in *"in less uncertain environments"* (p. 566), e.g. the mature stage of an industry life cycle, business model types based on transfer of product ownership with limited additional services, such as the product-oriented Classic Long Life circular business model type for preserving product integrity proposed in section 4.6, would in most instances be sufficient. For many products, product-service based business models like these would also be sufficient in the early stages, i.e., the ferment and transition stages, of the industry life cycle. Cusumano et al. (2015) proposed, however, that *"in conditions of high uncertainty"* (p. 566), e.g., during extremely technologically turbulent ferment and transition stages of the industry life cycle or in case of highly expensive products, *"offering a service as a substitute for product purchase"* (p. 556) could also be useful as it offers a way out of a situation where customers are reluctant to commit to buying an unproven and often expensive new product.

Elsewhere in the literature, Reim et al. (2015) and Frambach, Wels-Lips and Gündlach (1997) agree with Cusumano et al.'s (2015) proposition and argue that service as a substitute for product purchase can be useful during the early stages of the industry life cycle. They do so, however, for different reasons, thereby suggesting that offering a service as a substitute for product purchase during the early stages of the industry lifecycle could also prove beneficial from a business-economic point of view in a host of scenarios other than the exceptional extremely high uncertainty and high price scenario indicated by Cusumano et al. (2015). Frambach et al. (1997) for example indicated that offering a new product to as part of a use-oriented or result-oriented PSS-based business model type in the introduction or early growth stages of the industry life cycle can be expected to enhance the *"trialability"* (Rogers, 2003, p. 16) of an innovation, i.e., *"the degree to which an innovation may be experimented with on a limited basis"* (Rogers, 2003, p. 16). As such, offering products in ways that limit the perceived risks, for example as part of PSS-based business model types that are tailored to the characteristics of specific customer segments (Frambach et al., 1997), can help to fuel the diffusion process (Rogers, 2003) and trigger critical mass (Golder & Tellis, 2004). Cusumano (2015) and Reim et al. (2015) highlighted that the fact that businesses of the use-oriented and result-oriented business model types retain ownership and control over the product provides additional business-economic benefits in the early stages of the industry life cycle. It allows companies to test alternative solutions, gain *"insights into customer habits when using the product"* (Reim et al., 2015, p. 69), *"establish performance metrics that customers rely on to evaluate the value of the products"* (Cusumano et al., 2015, p. 561) offered and collect *"data on service design"* (Reim et al., 2015, p. 69) that can all be fed back into the product innovation process and *"increase the speed of innovation"* (Reim et al., 2015, p. 69).

Summarizing, the current literature provides indication that the extent to which a particular design direction (for preserving product integrity) can be expected to be successful when used in conjunction with a particular PSS-based business model type depends on:
- The type of PSS-based business model (e.g., Bocken et al., 2016; Reim et al., 2015; Kuo, 2011; Azarenko et al., 2009; Evans et al., 2007; Aurich et al., 2006);
- The, product type dependent, design cycle of the tangible product (Xing et al., 2005; Rose & Iishi, 1999);
- The (stage of the) technology cycle of the technology used in the tangible product that is to be designed (e.g., Xing et al., 2005; Rose & Iishi, 1999);
- the (stage of the) economic product life cycle pertaining to a particular tangible product (e.g., Eger & Drukker, 2012, 2010).

According to the literature, all three design directions of resisting, postponing and reversing are important to all three types of PSS-based business models, whereby the literature does indicate that application of the design directions is more important to use-oriented and result oriented PSS-based business model types than to product-oriented PSS-based business model types (Reim et al., 2015). According to Eger and Drukker (2010), the design direction of resisting obsolescence gains importance in the later stages (i.e., maturity and decline) of what they referred to as *"the economic product life cycle"* (p. 47). Eger and Drukker (2010), however, did not differentiate their assertions by types of PSS-based business models.

The extent to which a particular PSS-based business model type can be expected to be successful, according to the current literature, depends on:
- the type of tangible product (Antikainen et al., 2015);
- the (stage of the) industry life cycle pertaining to a particular tangible product (Cusumano et al., 2015; Reim et al., 2015; Tukker at al., 2006; Frambach et al., 1997)

A visual representation of the interdependencies between PSS-based business model types, life cycle stages and product types affecting the success of applied design directions as documented in the current literature and discussed above is shown in figure 6.4.1.

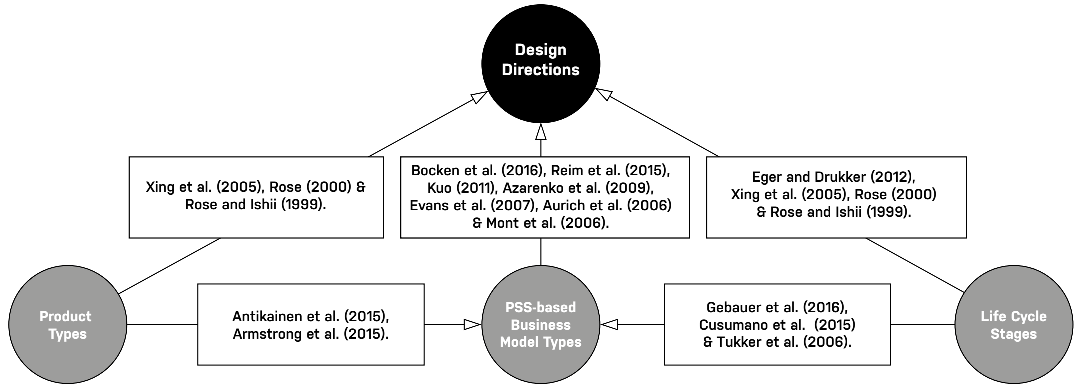


Figure 6.4.1: A visual representation of the interdependencies between PSS-based business model types, life cycle stages and product types affecting the success of applied design directions as documented in the current literature. The rounded rectangles contain references to research into the relationships between entities that is discussed in the current sub-section.

Although the current literature on (sustainable) product design and PSS-based business model types indicates a number of (interdependent) factors that influence to what extent combinations of design directions (for preserving product integrity) and PSS-based business model types will be successful (see figure 6.4.1), it is inconclusive with regard to which *specific* design directions can successfully be used in conjunction with *particular* product types, *particular* types of PSS-based business models and *particular*, product related, life cycle stages. As such, the literature on (sustainable) product design and PSS-based business models at present does not provide sufficient theoretical and/or empirical data for constructing a design method that can provide guidance to industrial designers (and other business professionals) in selecting design directions and circular business model types for preserving product integrity when designing for managing obsolescence.

In the remainder of this section, we will continue to development the design method as we envision it. However, for lack of conclusive theoretical and/or empirical evidence from the current literature to support it, we will present our design method as a conceptual proposition.

6.4.2 Developing a Heuristic Framework for Design for Managing Obsolescence

The literature review presented in sub-section 6.4.1 indicates that the extent to which particular combinations of design directions and circular business models for preserving product integrity are successful from a business-economic perspective depends on the type of product and the life cycle stages associated with the product under consideration (see figure 6.4.1). We therefore continued the development of our design method by expanding our literature review to include literature on product types (e.g., WIPO, 2017; Mason, 2005; Murphy & Enis, 1986; Hirschman & Holbrook, 1982; Darbi & Karni, 1973; Nelson, 1970; Copeland, 1923) and life cycle theory (e.g., Taylor & Taylor, 2012; Moon, 2005; Golder & Tellis, 2004; Rogers, 2003; Capon, 1985; Abernathy & Utterback, 1978) to find out to what extend it contained information that could be helpful in determining in what way product types and life cycle stages associated with the product under consideration affect the extent to which design direction are successful. Of these two streams of literature, we found the literature on product life cycle theory (e.g., Taylor & Taylor, 2012; Moon, 2005; Golder & Tellis, 2004; Rogers, 2003; Capon, 1985; Abernathy & Utterback, 1978) to be most useful here as it contains a rich discussion of (changes in) products and business-economic context over time on a general level (i.e., not pertaining to specific instances of a product) and for this reason (despite sometimes fierce criticism (e.g., Dhalla & Yuspeh, 1976)) is widely used by business professionals to support the process of developing product and business strategy (Taylor & Taylor, 2012, Capon, 1985; Hofer, 1975) (see Appendix C: The Strategy Concept: Definition, Evolution and Ontology and Appendix E: The Product Life Cycle and Related Concepts). (The current literature on product types presented several classification schemes and multiple types of products but does not provide information that helped to assess the extent to which design direction and circular business model types could be expected to be successful.)

The usefulness of product life cycle theory for guiding industrial designers when designing for managing obsolescence lies in the notion that is at the core of life cycle theory, i.e., the idea that all products and the technologies that they embody go through a number of distinct stages from the moment they are conceived and introduced into the market until they are removed from the market (e.g., Taylor & Taylor, 2012; Golder & Tellis, 2004; Rink & Swan, 1979; Buzzell, 1966).

As these various stages exhibit specific characteristics and often occur in a particular order, we found the findings from the business sciences literature on product life cycle theory useful in providing guidance to industrial designers (and other business professionals) when designing tangible products for managing obsolescence. Although views differ in the literature on what drives the occurrence of its different stages (Cusumano et al., 2015; Taylor & Taylor, 2012; Windrum & Birchenhall, 1998), the characteristics of the specific stages and the order in which they tend to occur can help industrial designers anticipate and prepare for changes in the market context over time, thus reducing the risk of a newly designed product from becoming obsolete *before its time.*

However, as we can proceed only on the basis of incomplete (e.g., discriminating by life cycle stage but not by product type) and non-validated information, we propose our method for design for managing obsolescence as a conceptual proposition in the form of a set of *design heuristics* (Yilmaz, Daly, Seifert, & Gonzalez, 2016; Simon & Newell, 1958). Design heuristics are "*mental shortcuts"* (Yilmaz et al., 2016, p. 96), that *"do not so much rely upon theoretical first principles as on experience and rules of thumb"* (Lawson, 1980, p. 132). They aim to "*capture cognitive strategies*" (Yilmaz et al., 2016, p. 96) and *"patterns common in successful design solutions ... linking the designer to a broad range of helpful guidance from past solutions in a refined form*" (Yilmaz et al, 2016, p. 96). Because of their nature, design heuristics may not always directly lead to the most optimal solution (Yilmaz et al., 2016, referencing Nisbett & Ross, 1980). Their primary usefulness resides in that they provide sensible starting points in the search for viable solutions and *"can help designers generate more, and more varied, candidate concepts to consider in the early phases of design"* (Yilmaz et al., 2016, p. 95).

The design method that we present here, i.e., a *heuristic framework for design for managing obsolescence*, is constructed from a set of inferences with regard to the extent to which design directions for preserving product integrity can be expected to be successful when used in conjunction with specific circular business model types for preserving product integrity. These inferences are based on careful reflection in the light of the secondary data and the authors' 20 years industry knowledge. We acknowledge that, as such, the newly proposed heuristic framework for design for managing obsolescence at present lacks – and therefore is in need of future – theoretical and empirical validation, however, we consider these tasks to lie outside the scope of the present thesis.

The Product Life Cycle Concept in the Literature from the Business Sciences

The literature from the domain of the business sciences contains three main different life cycle concepts, i.e., *"industry life cycle, product life cycle and technology life cycle*" (Taylor & Taylor, 2012, p. 541), some of which were touched upon earlier in the thesis (see for example sub-sections 5.4.2 and 6.4.1). Although these concepts are interrelated – as explained for example by Taylor & Taylor (2012) – they are not the same (Taylor & Taylor, 2012). The industry life cycle plots *"the number of producers of a new product over time"* (Taylor & Taylor, 2012, p. 543) and *"measures the net entry rate of firms"* (Taylor & Taylor, 2012, p. 543) in a particular market. The product life cycle pertains to the sales volume or revenue generated by a product over time (Golder & Tellis, 2004; Rink & Swan, 1979) as measured at a certain *level of aggregation,* such as *product model*, *product (sub-) category* and *brand* (Capon, 1985) (see Appendix E: The Product Life Cycle and Related Concepts). The technology life cycle reflects *"technological evolution, technology progression within industries and industry evolution"* (Taylor & Taylor, 2012, p. 543). Despite their differences, the three life cycle concepts are often used *"interchangeably, ambiguously and often inappropriately"* (Taylor & Taylor, 2012) in the literature, whereby *"a lack of normalised and consistent terminology, separation between the views of different stakeholder disciplines, ill-definition and transposition between terms and ambiguous or unspecified units of analysis have all contributed to confusion and misunderstanding in the field"* (Taylor & Taylor, 2012, p. 542). We consider a detailed discussion of the different life cycle conceptualizations and the differences between them, however, to lie outside the scope of the thesis, as it belongs to a different scientific domain (i.e., business sciences) than that of the thesis (i.e., (sustainable) product design) and furthermore is presented elsewhere in the literature (see for example Taylor & Taylor (2012)).

For the development of the heuristic framework for design managing obsolescence we will consider life cycle theory from the product life cycle perspective at the aggregation level of product (sub-) category. These concepts will be introduced briefly below. A more elaborate discussion of the product life cycle and related concepts, including a discussion of the origin of the concept, its validity and usefulness, is offered, however, in Appendix E: The Product Life Cycle and Related Concepts.

As mentioned above, the product life cycle pertains to the sales volumes or revenue created by a product over time (Golder & Tellis, 2004; Rink & Swan, 1979), measured at a certain *level of aggregation*. The product category level of aggregation consists of *"all products of all competing producers which, despite differences in appearance and performance, essentially serve a set of functional needs in a roughly similar manner*" (Capon, 1985, p. 1). According to Capon (1985)

> a set of basic customer needs is often met by a number of product categories. Typically, different product categories offer quite distinct customer benefits in satisfying common needs. Thus, for instance, passenger automobiles, bicycles, airplanes, railroads, ships, and motorcycles all provide consumer transportation. Other examples of product categories are conveyor belts, computers, audiotapes, and cameras (p. 1)

The product sub-category (Capon, 1985) level of aggregation consists of *"a homogeneous grouping of products from all competing producers that are more similar in how they are perceived and used by customers than items in a product category"* (Capon, 1985, p. 1). For example, *"within the product category of automobiles are the subcategories of sports cars, luxury cars, compacts, and subcompacts; within the product category of computers are the subcategories of mainframe, mini-/micro-, and personal computers"* (Capon, 1985, p. 1).

The product life cycle can be visually represented by the *product life cycle curve*. In its most commonly used "classical" (Tellis & Crawford, 1981; Rink & Swan, 1979) variant, the product life cycle curve is *"a bell-shaped curve that is divided into several stages"* (Rink & Swan, 1979, p. 220; Taylor & Taylor, 2012; Tellis & Crawford, 1981). In the product life cycle literature, the number of proposed stages varies between four and six (e.g., Taylor & Taylor, 2012; Moon, 2005; Golder & Tellis, 2004; Capon, 1985; Kotler, 1984; Rink & Swan, 1979; Polli & Cook, 1969; Levitt, 1965). However, in line with Taylor and Taylor (2012), Moon (2005), Golder and Tellis (2004), Kotler (1984), Rink and Swan (1979) and Levitt (1965), we adopt a division into four stages here. According to Golder and Tellis (2004), *"these* [four] *stages occur due to well-defined events in the history of a new product"* (p. 208). Golder and Tellis (2004) defined the four product life cycle stages as

> 1. Introduction is the period from a new product's commercialization until takeoff.
> 2. Growth is the period from a new product's takeoff until its slowdown in sales.
> 3. Maturity is the period from a product's slowdown until sales begin a steady decline.
> 4. Decline is the period of steadily decreasing sales until a product's demise (p. 208).

and the three *"well-defined events ...which mark the beginning and end of the first two stages"* (p. 208) as

> 1. Commercialization is the point at which a new product category is first sold to consumers.
> 2. Takeoff is the point of transition from the introduction to the growth stage of the PLC [*product life cycle*]. It is the first dramatic and sustained increase in product category sales.
> 3. Slowdown is the point of transition from the growth stage to the maturity stage of the PLC. The slowdown signals the beginning of a period of level, slowly increasing, or temporarily decreasing product sales (p. 208).

Figure 6.4.2 shows a classical product life cycle curve (Rink & Swan, 1979) with the four stages, i.e., *introduction*, *growth*, *maturity* and *decline* (Taylor & Taylor, 2012; Golder & Tellis, 2004; Kotler, 1984; Rink & Swan, 1979), and three key events, *commercialization*, *takeoff* and *slowdown* (Golder & Tellis, 2004) marking the beginning and end of the first two stages. Also indicated in figure 6.4.2 is the approximate emergence of what is known in the literature as the *dominant design* (Taylor & Taylor, 2012; Kim, 2003; Anderson & Tushman, 1990; White, 1979; Abernathy & Utterback, 1978). At the (early) growth stage of a new product category, certain consistently more successful product models can begin to dominate a product (sub-) category or even spawn whole new product sub-categories (Windrum & Birchenhall, 1998). When this happens, the design and/or the technology employed in such a product model becomes the dominant design within a (new) sub-category (Taylor & Taylor, 2012; Windrum & Birchenhall, 1998). From the moment of its emergence, this dominant design will function as the archetype for all other products, e.g. product models that come after it in the same product (sub-) category. The dominant design often is that particular model that at the same time allows industry to adequately satisfy the needs of the greatest number customers and that can be manufactured in sufficient numbers against the lowest cost (Abernathy & Utterback, 1978).

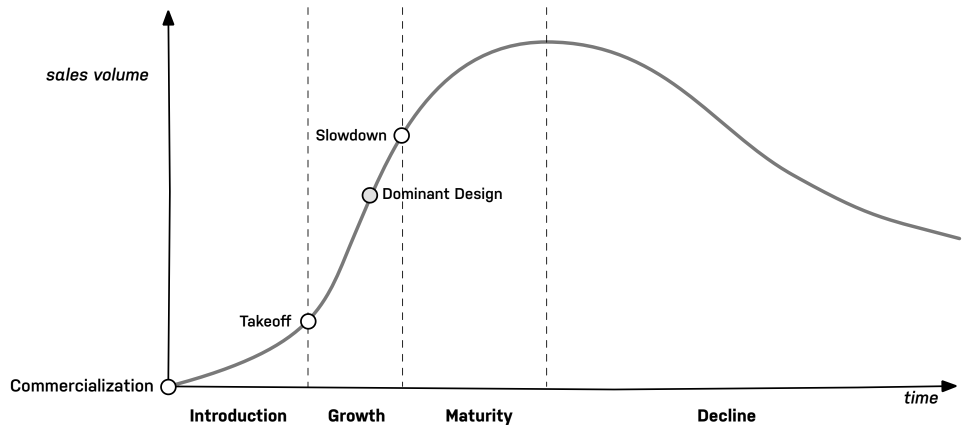


Figure 6.4.2: Classical product life cycle curve (Tellis & Crawford, 1981; Rink & Swan, 1979) with the four product life cycle stages, introduction, growth, maturity and decline (Golder & Tellis, 2014; Moon, 2005; Kotler, 1984; Rink & Swan, 1979; Levitt, 1965) the three events, commercialization, takeoff and slowdown, marking the beginning and end of the first two stages (Golder & Tellis, 2014) including the approximate emergence of the dominant design (Taylor & Taylor, 2012; Kim, 2003; Anderson & Tushman, 1990; White, 1979; Abernathy & Utterback, 1978).

It is not often that the introduction of a newly designed product brings about the emergence of a whole new product category (Abell, 1980). In the rare instances that it does, the introduction of newly designed product model coincides with the beginning of the introduction stage of a new product category life cycle curve. In most instances, however, newly designed products are designed to compete in and be launched into an already existing product category that, at the moment the newly designed product is introduced, is already at any of the other three product category life cycle stages that follow the introduction stage, i.e., growth, maturity or decline (Abell, 1980). As these stages have their own particular characteristics (e.g., type and rate of technological innovation, types of users/adopters (see Appendix E: Product Life Cycle and Related Concepts)) and tend to occur in a certain order, they provide a (time-dependent) business-economic context for newly designed products that allow us to make inferences with regard to the extent to which particular design directions and circular business models for preserving product integrity can be expected to be successful. These inferences can subsequently be used in constructing a heuristic framework for design for managing obsolescence.

Inferences with Regard to Design Interventions for Preserving Product Integrity and Circular Business Model Types for Preserving Product Integrity Based on the Four Product Category Life Cycle Stages

In this paragraph, we will discuss the characteristics of the four product life cycle stages (for a more extensive discussion see Appendix E: The Product Life Cycle and Related Concepts) and the inferences with regard to the extent to which a particular circular business model type can be expected to realise a potential for preserving product integrity and the extent to which a potential created by a particular design directions can be expected to be realised, as they can be made based on the characteristics of the four product category life cycle stages, i.e., introduction, growth, maturity and decline.

The Introduction Stage

In this early stage of the development of a market for a new product (sub-) category, *"the market volume is low and there are high levels of uncertainty"* (Taylor & Taylor, 2012, p. 543), both on the producer and consumer side (Windrum & Birchenhall, 1998). At this stage, the business is focused on creating a new and innovative product (sub-) category that people can relate to and appreciate (Moon, 2005; Levitt, 1965), educating the market, i.e., *"getting consumers to try the product"* (Levitt, 1965, p. 4) and build brand identity (Moon, 2005). Innovation in companies is targeted at improving the product rather than the production process (Taylor & Taylor, 2012; Abernathy & Utterback, 1978). The market at this point is characterized by *"a diverse and responsive group of enterprises* [struggling] *against established units to enter industry"* (Abernathy & Utterback, 1978, p. 4) and both product and market are ill-defined (Capon, 1985; Utterback & Abernathy, 1978): *"most new industries in stage I* [i.e., the introduction and early growth stages] *of a* [product category] *life cycle are characterized by significant uncertainty regarding market size, product design, consumer tastes and technological constraints"* (Windrum & Birchenhall, 1998, p. 110). On the customer side, there is uncertainty about the performance of the new products and the overall viability of the new product category. *"This typically leads to a variety of designs being offered, reflecting different firms' bets about the future"* (Windrum & Birchenhall, 1998, p. 110). Sales volumes are typically low and show little progress (Levitt, 1965). In the introduction stage, the presence of (potential) competitors can however be helpful, because *"generally speaking, the more producers there are of a new product, the more effort* [and (financial) resources go] *... into developing a market for it"* (Levitt, 1965, p. 10). Especially in the introduction stage, "*customers may be fearful that the new product will not perform adequately"* (Capon, 1985, p. 4). Research shows that their fears might not be without ground, as new technology at its introduction often does not (yet) perform as well and reliably as the existing solutions it is attempting to replace (Sood & Tellis, 2005). In the introduction stage of a new product category, new products are therefore acquired by adopters of Rogers' (2003) *innovator* category, i.e., users that are *"venturesome"* (Rogers, 2003, p. 283) and have *"a desire for the rash, the daring and the risky"* (Rogers, 2003, p. 283). These innovators have *"substantial financial resources"* (Rogers, 2003, p. 282) available to them, allowing them to fulfil their craving for new and innovative products. Despite their intense interest in new products, these innovators tend to move on to the next new product as soon as the novelty of a product has worn off (Rogers, 2003).

Although the attention span of the innovators for a particular new product category may be short, it is, however, deep. With their substantial *"technical competence"* (Rogers, 2003, p. 27) innovators often are as interested in the workings and the development of the product itself as they are in what the product can actually do for them. As such, it can prove advantageous for a business to make use of the (technical) knowledge and interest of the adopters of the innovator category in shaping and improving the product-service combination that the business is introducing (Cusumano et al., 2015; Reim et al., 2015). In the introduction stage, it typically is a start-up or fledgling division of a larger company (Abernathy & Utterback, 1978) that introduces the new product that (potentially) is the start of a new product category. The actual business model for the developing business often is as much under construction as is the product itself, as companies are busy devising, deploying and evaluating different strategies aimed at *"getting consumers to try the product"* (Levitt, 1965, p.4).

Inferences Based on the Characteristics of the Introduction Stage

The interaction between manufacturer/provider and user that is inherent in the nature of the use-oriented and result-oriented circular business model types can make the Access model and the Performance model (see sub-sections 4.6.2 and 4.6.3) ideal platforms for building a (long-term) relationship and creating rapport with the users. The relationship allows innovators to become part of the product development process and companies to make use of their, often knowledgeable, input and insights to rapidly and effectively improve their products, for example through presenting their new product in the form of a *"minimum viable product"* (Ries, 2011, p. 4; Moogk, 2012), defined by Ries (2009) as *"that version of a new product which allows a team to collect the maximum amount of valid learning about customers with the least effort"*. Contrary to Tukker et al. (2006), but in line with the findings of Cusumano et al. (2015), Reim et al. (2015) and Frambach et al. (1997) presented earlier, we therefore infer that in the introduction and early growth stages, circular business models based on the use-oriented Access business model type or on result-oriented Performance model type are more promising alternatives for realizing a potential for preserving product integrity that was designed into a product then those based on the product-oriented Classic Long Life business model type.

With regard to design directions, we infer that, based on the intense, but rapidly fleeting, interest in each new product model that characterizes the innovator adopter category (Rogers, 2003), and on the medium to high rate of product innovation in the introduction stage (Taylor & Taylor, 2012; Capon, 1985; Abernathy & Utterback, 1978), the design directions of resisting, postponing and reversing obsolescence can be expected to be successful in the introduction and early growth stages of the product category lifecycle only when used in conjunction with business models of the Access or Performance type, as these retain economic control over the tangible product and use tangible products as means of production, and therefore generally much more intensively than business models of the Classic Long Life model type.

However, due to the increasingly high level of (technological) turbulence and rate of innovation (Taylor & Taylor, 2012; Capon, 1985; Abernathy & Utterback, 1978) that characterize the introduction stage, we infer these design directions to be successful to a limited extent only.

Table 6.4.2 presents an overview of our inferences for the introduction stage.

Introduction stage	Resisting obsolescence	Postponing obsolescence	Reversing obsolescence
Classic Long Life model	●○○	●○○	●○○
Access model	●●○	●●○	●●○
Performance model	●●○	●●○	●●○

Legend:

= high expectation of success = medium expectation of success = low expectation of success

●●● = high expectation of successful realisation and high relative importance within overall design intention

●●○ = medium expectation of successful realisation and medium relative importance within overall design intention

●○○ = low expectation of successful realisation and low relative importance within overall design intention

Table 6.4.2: Overview of our inferences for the introduction stage. The coloured rectangle indicates the extent to which a specific circular business model type can be expected to realise a potential for preserving product integrity in a particular product category lifecycle stage. The number of black dots indicate the extent to which a particular potential for preserving product integrity that was designed into a product can be expected to be successfully realised by a specific circular business model type in a particular product category life cycle stage and thus provides an indication of the relative importance that should be assigned to a particular design direction in designing a new product for that particular combination of circular business model for preserving product integrity and product category life cycle stage.

The Growth Stage

In the growth stage, the business challenges shift to getting consumers to prefer the particular brand of the product and business under consideration and remain loyal to it over time (Moon, 2005; Levitt, 1965), successfully creating or copying the dominant design (Windrum & Birchenhall 1998; Capon, 1985; Abernathy & Utterback, 1978; Levitt, 1965) and handling the accelerating demand (production and distribution) (Capon, 1985; Abernathy & Utterback, 1978). Although the takeoff point (Golder & Tellis, 2004; Levitt, 1965) has now been passed, the new technology often still does not perform as well and reliably as the existing solutions it is attempting to replace (Sood & Tellis, 2005). Together with the need for differentiation (Taylor & Taylor, 2012; Capon, 1985; Levitt, 1965) the need for further product development results in even more rapid and frequent product changes that in the introduction stage (Taylor & Taylor, 2012; Abernathy & Utterback, 1978), rendering earlier versions of the product obsolete at a fast pace.
Adopters in the growth stage are of the *early adopter* and *early majority* categories (Rogers, 2003). Although these adopter categories have sufficient financial means (Rogers, 2003), they are more hesitant in embracing new products than their more affluent and newness addicted innovator counterparts (Rogers, 2003). Additionally, many users in Western style economies have over time experienced and thus become aware of the increasing rate at which products tend to become obsolete (Schridde, 2014), especially those product models belonging to recently introduced product sub-categories of certain highly dynamic product categories such as consumer electronics (Wang et al., 2013). We therefore infer that adopters from the early adopter and early majority categories will be hesitant to pay a premium for product longevity of new products in the early growth stages of product (sub-) categories, especially in the context of a (higher investment risk) product-oriented, Classic Long Life, circular business model type for preserving product integrity, unless the product is shown to be future-proof, e.g. is designed with a potential for postponing obsolescence and accompanied by a clearly communicated roadmap for realizing this potential. This may change, however, later on in the growth stage when a dominant design (Taylor & Taylor, 2012; White, 1979; Abernathy & Utterback, 1978) has been established and the course of a particular product category has become clearer and the investment risk has lessened.

With an increasing and accelerating demand for their products in the growth stage, however, companies face the new challenge of satisfying this demand (Capon, 1985). An inability to satisfy the accelerating demand presents a risk as it could create opportunities for unwanted competition to enter the rapidly growing market (Capon, 1985). Often, newly introduced products suffer from early manufacturing or *teething* defects. These could undermine the business goals of achieving brand preference and meeting the rising demand and prove costly as under European consumer law (Europa, 2017), products that break down during the first two years of their product lifetime as result of *"chargeable failures"* (Moss, 1985, p. 14), e.g. *"failure*[s] *that can be attributed to a defect in design or manufacture"* (Moss, 1985, p. 14), have to either be repaired or replaced under warranty.

Inferences Based on the Characteristics of the Growth Stage

With regard to circular business model types, we infer that, especially in the later growth stage after a dominant design has been established and the technological turbulence and uncertainty lessens, the extent to which business models of the product-oriented, Classic Long Life, business model type can be expected to be successful. i.e., to realise a potential for preserving product integrity designed into a product, increases as compared to the introduction stage, bringing it more on par with that of business models of the use-oriented Access model and result-oriented Performance model type.

Based in the above, we infer that designing a potential for postponing and reversing obsolescence, especially for upgrading, repair, recontextualizing, refurbishment and remanufacturing, can be expected to be successful when applied to newly designed products that are intended to be introduced to the market in the growth stage of a product category. These design directions can help relieve some of the pressure of satisfying rising demand as they allow products that otherwise would have become obsolete to be kept in use for longer and allow products that have become obsolete to be fed back into the market, i.e., recontextualized or refurbished, to help meet the increasing demand at a time when budding businesses are often struggling to ramp up their production capacities fast enough. As the growth stage has the highest rate of fundamental product innovation (Taylor & Taylor, 2012; Capon, 1985; Abernathy & Utterback, 1978) and building brand preference is of prime importance (Moon, 2005; Levitt, 1965), we furthermore infer that – especially in light of the teething defects mentioned above – it can therefore be profitable for circular business models for preserving product integrity to make use of products that are designed for postponing and/or reversing obsolescence in order to help reduce business service cost, shorten turn-around times and improve customer service perception. As such, we infer that for product-oriented, use-oriented and result-oriented circular business model types, design interventions for postponing and reversing obsolescence can be expected to be more successful in the growth stage than in the introduction stage. However, in view of the even higher rate of product innovation in the growth stage than in the introduction stage, we infer that the extent to which design direction of resisting obsolescence can be expected to be successful is overall still limited. Similar to the introduction stage, we infer that the design directions of postponing and reversing obsolescence again can be expected to be more successful for use-oriented and result-oriented circular business model types like the Access model and the Performance model than for the product-oriented Classic Long Life model because of the way tangible products are used in these business model types.

Growth stage

	Resisting obsolescence	Postponing obsolescence	Reversing obsolescence
Classic Long Life model	●●○	●●○	●●○
Access model	●●○	●●●	●●●
Performance model	●●○	●●●	●●●

Legend:

= high expectation of success   = medium expectation of success   = low expectation of success

●●● = high expectation of successful realisation and high relative importance within overall design intention

●●○ = medium expectation of successful realisation and medium relative importance within overall design intention

●○○ = low expectation of successful realisation and low relative importance within overall design intention

Table 6.4.3: Overview of our inferences for the growth stage. The coloured rectangle indicates the extent to which a specific circular business model type can be expected to realise a potential for preserving product integrity in a particular product category lifecycle stage. The number of black dots indicate the extent to which a particular potential for preserving product integrity that was designed into a product can be expected to be successfully realised by a specific circular business model type in a particular product category life cycle stage and thus provides an indication of the relative importance that should be assigned to a particular design direction in designing a new product for that particular combination of circular business model for preserving product integrity and product category life cycle stage.

The Maturity Stage

With the onset of the maturity stage, there is a typical shift in the focus of innovation from product to process (Taylor & Taylor, 2012; Abernathy & Utterback, 1978). The uncertainty of the preceding introduction and growth stages, both on the consumer and the manufacturer side, with regard to desired product performance and characteristics has subsided (Taylor & Taylor, 2012; Windrum & Birchenhall, 1998; Abernathy & Utterback, 1978). Fending off competition, retaining or increasing market share, increasing distribution and increasing profitability by reducing cost become the primary aims for a business (Capon, 1985; Abernathy & Utterback, 1978; Levitt, 1965). The market is segmented to the extent of being fragmented (Moon, 2005; Windrum & Birchenhall, 1998), each (niche) segment, or product (sub-) category, with its own dominant design (Windrum & Birchenhall, 1998; Abernathy & Utterback 1979). With the onset of the maturity stage the saturation point of the market (Peres, Muller & Mahajan, 2009; Golder & Tellis, 2004) is in sight. Once that point is reached, replacement sales will dominate the market and the product (sub-) category is at risk of becoming stagnant (Hamermesh & Silk, 1979) and go into decline. The remaining business competitors look to protect, and harvest from, their investments from the previous stages for a long as possible and have little interest in disrupting of the product (sub-) category. In this stage of the product category life cycle, basic product requirements are clear and virtually frozen. The frequency of fundamental product innovations is therefore at its lowest (Taylor & Taylor, 2012; Abernathy & Utterback, 1978), reducing the risk of products becoming obsolete *before there time*, i.e., earlier then was planned in the obsolescence profile, either because lack of functionality or loss of environmental advantage. This all fits seamlessly with the characteristics of the *late majority* and *laggard* adopter categories prevalent in the maturity stage: A low desire for innovativeness and average to limited financial resources (Rogers, 2003).

With the core functionality for the product (sub-) category now solidly established (Taylor & Taylor, 2012; Golder & Tellis, 2004; Windrum & Birchenhall, 1998; Abernathy & Utterback, 1978), changes in product models mostly concern styling or secondary feature changes, sometimes resulting in *"featuritis"* (Buschmann, 2010, p. 1), i.e., the adding of more and more relatively meaningless functionalities. For many products (sub-) categories in the maturity stage, for example refrigerators and light fixtures, enduring user involvement has long since waned (Richins & Bloch, 1986). This makes not owning the *latest and greatest* unimportant and using the same product for an extended period of time generally acceptable to most users, especially if this long use is facilitated by opportunities for maintenance, repair and upgrading.

Inferences Based on the Characteristics of the Maturity Stage

In line with Cusumano et al. (2015), Reim et al. (2015), Tukker et al. (2006) and Frambach et al. (1997), we infer that because of the low rate of fundamental product innovation in the maturity stage, all three circular business model types for preserving product integrity, i.e., the Classic Long Life model, the Access model and the Performance model can be expected to be successful, i.e., realise a potential for preserving product integrity, in the maturity stage. Because the maturity stage is the most stable stage of the product category life cycle curve, with most of the established parties striving to maintain this stability (Capon, 1985), we furthermore infer that the maturity stage is the most favourable stage of the product category life cycle for product-oriented, use-oriented and result-oriented circular business model types for preserving product integrity alike. For business models of the Classic Long Life type the maturity stage is favourable as the reduced technological turbulence and risk of choosing the wrong product make paying a premium for a product with a potential for a long or extended lifetime a sensible option. As far as business models of the Access and Performance model types are concerned, the reduced rate of fundamental product innovation makes their tangible products are less prone to be overtaken by newer varieties, giving business models of these types time to realize the potentials for resisting, postponing and reversing

Maturity stage	Resisting obsolescence	Postponing obsolescence	Reversing obsolescence
Classic Long Life model (high expectation of success)	●●●	●●○	●●○
Access model (high expectation of success)	●●○	●●●	●●●
Performance model (high expectation of success)	●●●	●●●	●●●

Legend:

- [green] = high expectation of success
- [yellow] = medium expectation of success
- [red] = low expectation of success
- ●●● = high expectation of successful realisation and high relative importance within overall design intention
- ●●○ = medium expectation of successful realisation and medium relative importance within overall design intention
- ●○○ = low expectation of successful realisation and low relative importance within overall design intention

Table 6.4.4: Overview of our inferences for the maturity stage. The coloured rectangle indicates the extent to which a specific circular business model type can be expected to realise a potential for preserving product integrity in a particular product category lifecycle stage. The number of black dots indicate the extent to which a particular potential for preserving product integrity that was designed into a product can be expected to be successfully realised by a specific circular business model type in a particular product category life cycle stage and thus provides an indication of the relative importance that should be assigned to a particular design direction in designing a new product for that particular combination of circular business model for preserving product integrity and product category life cycle stage.

obsolescence that they have designed and manufactured into their products as they have full economic control over their products.

Because of this inherent stability of the maturity stage, we infer that the characteristics of the maturity stage are favourable to the design directions of resisting obsolescence, postponing obsolescence and reversing obsolescence alike. However, there remains a lingering uncertainty whether potentials for postponing and reversing obsolescence that have been designed and manufactured into products will indeed be realized in product-oriented, Classic Long Life circular business model type for preserving product integrity. In these types of business models, (economic) control over products is relinquished to the consumer and so there is no way to enforce the (timely) performance of maintenance or repair or a (timely) return to the manufacturer of products for refurbishing or remanufacturing. We therefore infer that the design directions postponing or reversing obsolescence can be expected to be less successful in circular business models based on the Classic Long Life model type than in those of the Access model or Performance model type. As in business models of the Access model type, users operate the tangible products involved and are therefore often allowed to express a preference for a particular product, there is a certain risk that users will refuse to use a product that they perceive as too old or that looks too used to their eyes, although it is in perfect condition from an objective, technical point of view. As such, we infer that the design direction of resisting obsolescence can be expected to be less successful in Access model based business model types than in those based on the Performance model as products are likely to need an occasional *brush-up* to remain attractive.

The Decline Stage

When users lose interest in the products of a product (sub-) category and the number of sales dwindles, the decline stage sets in. Within some product (sub-) categories, *"growth segments"* (Hamermesh & Silk, 1979, p. 5) will remain. Viewed on product (sub-)category level, as argued by Harrigan and Porter (1983), those (niche) growth segments within the overall declining product category are not actually in the decline stage, but rather can be considered as being in the growth stage.

In this paragraph on decline, however, we are not concerned with those growth segments, but instead are concerned with specific and often niche *"demand pockets"* (p. 5) with a *"favorable structure"* (p. 5) as described by Harrigan and Porter (1983), that can remain remarkably stable for a long time (Anderson, 2008) in stagnant or declining product (sub-) categories.

According to Harrigan and Porter (1983), the customers that remain during the decline stage of a product (sub-) category and that create these favourable pockets of demand are *"price insensitive"* (p. 5), either because they are *"immune to substitute products and brand loyal"* (p. 5), or *"have little bargaining power"* (p. 6) (see Appendix E: The Product Life Cycle and Related Concepts). As a result, the pressure of the price-based competition as well as *featuritis*, both characteristic of the maturity stage, ease off during the decline stage in these favourable pockets of demand (Harrigan & Porter, 1983). Often, customers that remain are loyal to a particular product and/or a brand because they expressly want or need it as part of their daily lives. This can for example be because it caters to their emotional needs, helps express their identity, e.g. fits with their lifestyle (Mugge, 2007), or because they need the product to keep (an eco-system of) other products that are important to them in working condition (Bartels et al., 2012) (see sub-section 5.4.3). As such, these customers are often prepared to pay a premium for a potential for longevity designed and manufactured in the product under consideration. As many these products often require limited additional research and development (the frequency of fundamental innovations is extremely low) introduction and the production facilities have been optimized in earlier stages, process cost can be kept low. However, as the numbers of (potential) customers go down, the volumes go down. It becomes harder for use-oriented and result-oriented PSS-based businesses to effectively and efficiently (i.e., profitably) provide their product-service combinations, especially since the remaining users expect a consistent high grade and high-quality result. There is uncertainty about the return on investments in products as means of production, and the particular products will often become more difficult and expensive to maintain and repair as they are no longer mainstream (Bartels et al., 2012).

Inferences Based on the Characteristics of the Decline Stage

Based on the above, we infer that the conditions of the decline stage generally are unfavourable to business models based on the use-oriented or result-oriented types of circular business models for preserving product integrity, i.e., the Access and Performance model, and that as such the extent to which they can be expected to be successful in realizing a potential for preserving product integrity that was designed into new products intended to be introduced In this stage to the lowest level of the four stages of the product category life cycle.
By contrast, we infer that the conditions of the decline stage are the most advantageous to the Classic Long Life, product-oriented, type of circular business model for preserving product integrity. Customers in the decline stage are often fiercely loyal to their products. These us-

Decline stage	Resisting obsolescence	Postponing obsolescence	Reversing obsolescence
Classic Long Life model	●●●	●●○	●●○
Access model	●●○	●○○	●○○
Performance model	●●○	●○○	●○○

Legend:

■ = high expectation of success ■ = medium expectation of success ■ = low expectation of success

●●● = high expectation of successful realisation and high relative importance within overall design intention

●●○ = medium expectation of successful realisation and medium relative importance within overall design intention

●○○ = low expectation of successful realisation and low relative importance within overall design intention

Table 6.4.5: Overview of our inferences for the decline stage. The coloured rectangle indicates the extent to which a specific circular business model type can be expected to realise a potential for preserving product integrity in a particular product category lifecycle stage. The number of black dots indicate the extent to which a particular potential for preserving product integrity that was designed into a product can be expected to be successfully realised by a specific circular business model type in a particular product category life cycle stage and thus provides an indication of the relative importance that should be assigned to a particular design direction in designing a new product for that particular combination of circular business model for preserving product integrity and product category life cycle stage.

ers need their products (albeit for different reasons, see above) and as such are often willing to pay a premium for them and want and/or need to keep them in good working order for a long time to come. As the connection to – often a particular instance of – a product is so strong, we deem it likely that these customers want to own their products instead of being dependent on them as part of an Access model or Performance model-based product-service value proposition.

With regard to design directions, we therefore infer that of all product category life cycle stages, the decline stage provides the best conditions for the design directions of resisting obsolescence, postponing obsolescence in conjunction with the product-oriented, Classic Long Life circular business model type. We infer furthermore that the design direction of reversing obsolescence is less likely to be successful in conjunction with a business model of the Classic Long Life type as the realization of a potential for reversing obsolescence often involve a change of ownership or requires the occurrence of substantial wear and tear as a result of intensive product use to justify interventions like remanufacturing, a scenario we deem unlikely in the instance of careful use by a single and involved, owner. For those products that for some reason are introduced as part of a business model of the Access or Performance model type in the decline stage of the product category life cycle, we infer that the design direction of resisting obsolescence can be expected to be successful to a limited extent as it helps prolong the useful lifetime of a product without requiring (potentially costly) interventions during the useful lifetime of the product

6.4.3 Presenting a Heuristic Framework for Design for Managing Obsolescence

As a last step in the development of our conceptual proposition of the design method of a heuristic framework for design for managing obsolescence, we propose to employ the three-dimensional space for preserving product integrity (see section 3.7 and figure 3.7.1) to represent the composition of the design directions in the overall design intention to create a visual overview of our inferences from sub-section 6.4.2. In this overview, the extent to which a particular type of circular business model can be expected to be successful and the extent to which specific design direction can be expected to be successful when used in conjunction with a particular type of circular business model are displayed simultaneously in order to provide guidance to industrial designers in selecting combinations of circular business model types and design direction to be used along the obsolescence profile.

Figure 6.4.3 shows a version of the heuristic framework for design for managing obsolescence that is based on the inferences presented in sub-section 6.4.2. Based on these inferences, the colour of the cube indicates the extent to which a particular circular business model can be expected to be successful in a specific product category lifecycle stage. The position of the cube on each axis indicates the relative importance of a particular design direction in the overall design intention and is an indication for the (type of) potential that can expected to be realised, for a newly designed product for introduction in a particular product category life cycle stage and in the context of a specific circular business model.

We know from the literature (see sub-section 6.4.1) that different product types could result in a different version of the heuristic framework as product type affects the extent to which particular combinations of PSS-based business model types and individual design directions can be expected to be successful (see figure 6.4.1). However, as data with regard to product category or type is not incorporated in the heuristic framework for design for managing obsolescence as presented here, it should be considered generic.

Comparing the Predictions from the Heuristic Framework with Existing Products

In this paragraph, we compare the results of our inferences represented in the heuristic framework with our earlier assessments of the composition of the design directions of the example products from non-circular business models as discussed in sub-section 3.7.2 and section 5.5 and shown in figure 3.7.2 to get a first indication of how well the predictions from our conceptual proposition match real world instances. Table 6.4.4 lists how we matched the non-circular business model from the examples with corresponding circular business model types (based on secondary data and interview results) and how we assessed the product category life cycle stage of the respective products for the comparison (based on industry experience of the author). The Fairphone 2 is assigned two product category lifecycle stages. Contrary to the other product examples from our sample, that all have a well-established core functionality, it is an example of a product that on the one hand can be considered to belong to a product (sub-)category (i.e., smartphones) that is in its maturity as the market is saturated, but on the other hand can be considered to belong to an upcoming product (sub-) category that is in the growth stage as it combines several, often still rapidly evolving, key technologies (Taylor & Taylor, 2012) that affect the product's overall functionality at a fundamental level. In the latter case, unequivocal categorization becomes more difficult, e.g., should it be considered a phone with added functionality to which secondary features are added with its new model iteration or would it be better classified as a powerful, pocket sized, modular computing platform with networking and communication capabilities? Both the

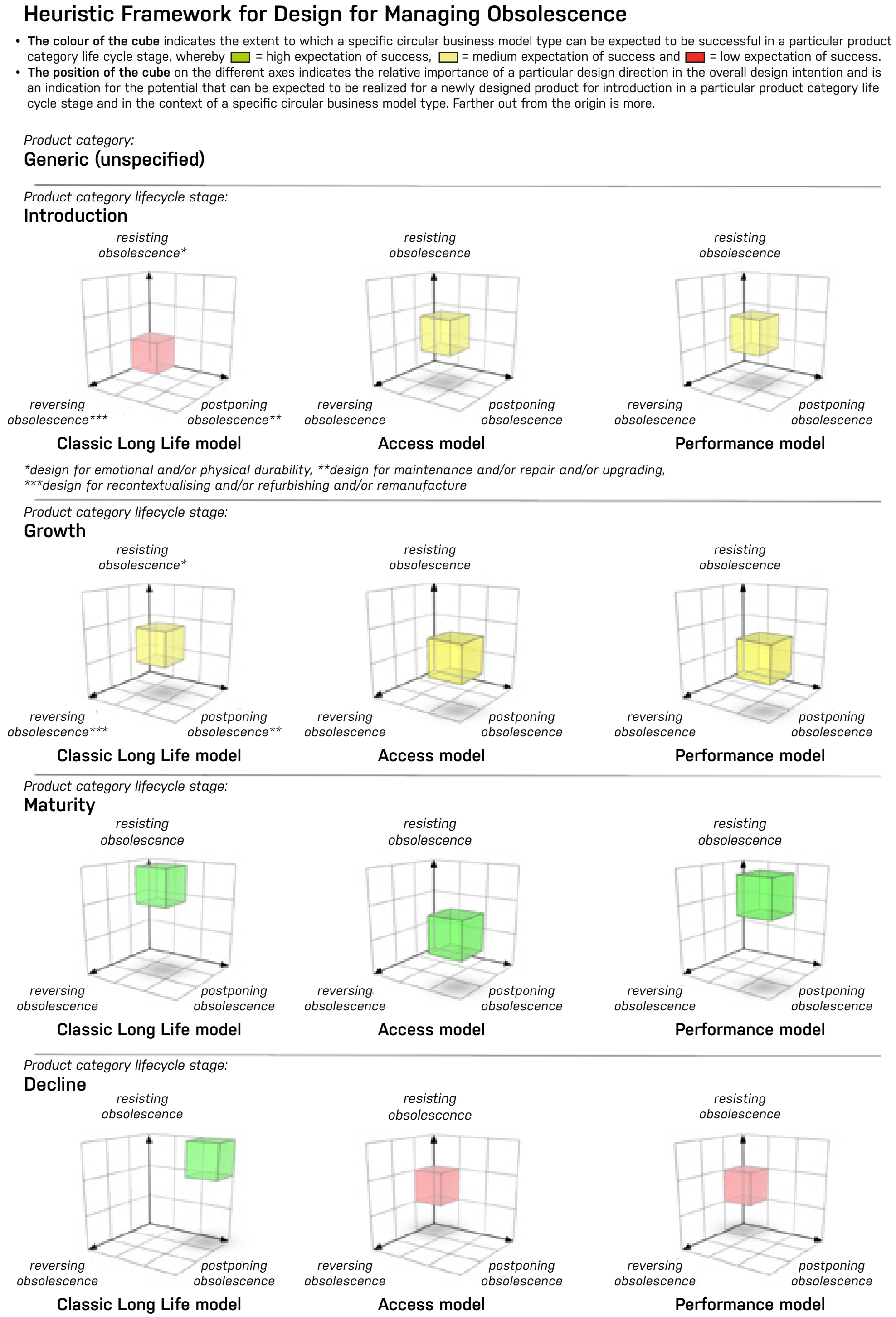


Figure 6.4.3: A heuristic framework for design for managing obsolescence based on the inferences presented in sub-section 6.4.2.

Océ copier and the BMA Ergonomics office chair are assigned two circular business model type equivalents in order to match what was said during the interviews (see sub-section 5.5.3). The Océ copier, although it is traded by selling the ownership rights, is often offered to the end user through a lease construction. BMA Ergonomics generally transfers the ownership rights to their products, however, also experiments with offering their products to the end user in a lease construction.

Product example	Circular business model equivalent	Product category life cycle stage
Vitsoe 606 wall shelving	Classic Long Life model	Decline
Saddleback leather bag	Classic Long Life model	Decline
Fairphone 2*	Classic Long Life model	Maturity
Fairphone 2*	Classic Long Life model	Growth
Miele washing machine	Classic Long Life model	Maturity
Eastpak backpack	Classic Long Life model	Maturity
Océ copier	Classic Long Life model	Maturity
Océ copier	Access model	Maturity
BMA Ergonomics office chair*	Classic Long Life model	Maturity
BMA Ergonomics office chair*	Access model	Maturity
Loewe television	Classic Long Life model	Decline
Tedrive steering unit	Classic Long Life model	Maturity

*Table 6.4.4: An overview of how the non-circular business models from the example products were matched with corresponding circular business models and how the product life cycle stages for the example products were interpreted for the comparison. Note: *The Fairphone 2 is assigned to two different product category life cycle stages and both the Océ copier and the BMA Ergonomics office chair are assigned two different equivalent circular business model types. See body text for explanation.*

Figure 6.4.4 displays a visual overview of the results of the comparison, that was created by overlaying the design space diagrams for the example products from figure 3.7.2 with the corresponding (see table 6.4.4) design space diagrams from the heuristic framework of figure 6.4.3.

From the many green cubes in the overview of figure 6.4.4, it is clear that in virtually all product instances (with the exception of the Fairphone 2 Classic Long Life/growth stage scenario), the long-life product is brought to the market in a business model-product category life cycle stage combination for which the expectation of success is marked as "high" in our conceptual proposition for the heuristic framework for design for managing obsolescence. The business model type used for the vast majority of the example product instances thus matches the business model type suggestion for a particular product category life cycle stage as made by the heuristic framework. As can furthermore be seen in figure 6.4.4, the comparison of the compositions of the overall design intentions as suggested by the heuristic framework and those assessed earlier in sub-section 3.7.1 results in an exact match for two of the twelve example product instances (i.e., Vitsoe 606 wall shelving and Océ copier in the Access model/maturity stage scenario). The suggested composition of the overall design directions that can be expected to be successful can be considered fairly close, and thus

- **The colour of the cube** indicates the extent to which the applied circular business model type equivalent (indicated below each figure) can be expected to be successful in a particular product category life cycle stage (indicated below each figure), whereby
  = high expectation of success, = medium expectation of success and = low expectation of success.
- **The position of the coloured cube** on the different axes indicates the relative importance of a particular design direction in the overall design intention and is an indication for the potential that can be expected to be realized for a newly designed product for introduction in a particular product category life cycle stage and in the context of a specific circular business model type as predicted by the heuristic framework for design for managing from figure 6.4.3. Farther out from the origin is more.
- **The position of the grey cube** on the different axes indicates the relative importance of a particular type of potential, e.g., a potential for resisting, postponing or reversing obsolescence, within the overall design intention for preserving product integrity for a specific example product and thus provides an indication of the extent to which it was designed into that product. Farther out from the origin is more.

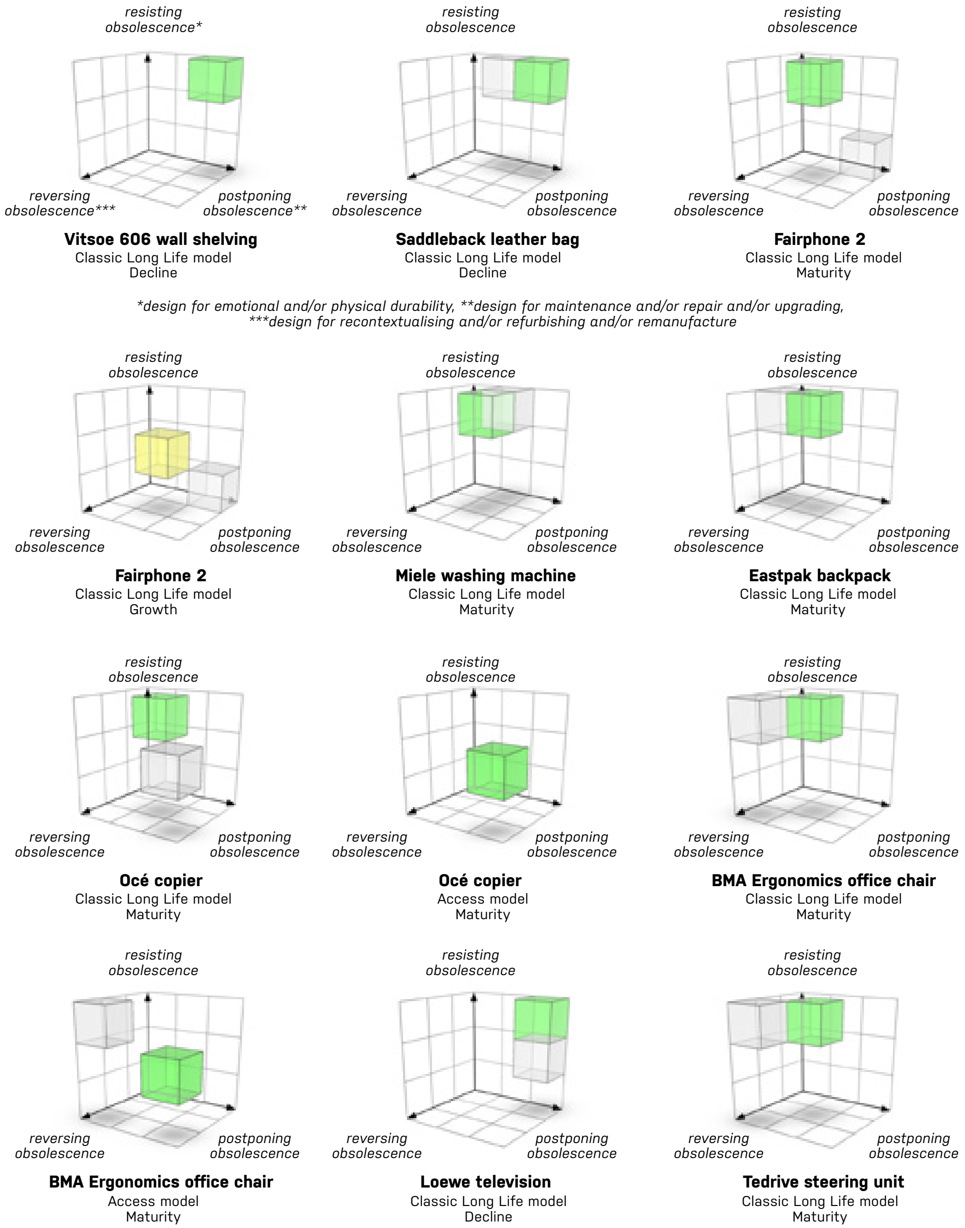


Figure 6.4.4: A comparison of the results of our inferences as represented in the heuristic framework from figure 6.4.3 with our earlier assessments of the example products (from non-circular business models) as shown in figure 3.7.2.

acceptable as a suggestion for a starting point for industrial designers when designing for managing obsolescence, in six of the product instances (i.e., Saddleback leather bag, Miele washing machine, Eastpak backpack, BMA Ergonomics office chair in Classic Long Life/maturity stage scenario, Loewe television and Tedrive steering unit). In four of the twelve product instances (i.e., Fairphone 2 in both scenario's, Océ copier in Classic Long Life/maturity stage scenario and BMA Ergonomic office chair in Access model/maturity stage scenario) the suggested combination of design directions that can be expected to be successful when applied in conjunction with a particular business model type and product category life cycle stage is farther off and as such has less or no value as a starting point for industrial designers.

Against the background of the company interviews (see section 5.5), the comparison from figure 6.4.4 also illustrates how management decisions can affect the combinations of design directions used with a particular circular business model type and thus can make for a worse or better match between the suggestion presented by the heuristic framework and reality.

In the case of the Miele washing machine for example, the decision of the Miele management not to remanufacture or refurbish their used units (see sub-section 5.5.1) makes the design intention for the Miele washing machine end up less far out from the origin on the reversing obsolescence axis than the current version of our heuristic framework for design for managing obsolescence suggests it could (see figure 6.4.5). Our conceptual heuristic framework in this instance would for example suggest to industrial designers (and other business professionals) that Miele management could consider setting up a refurbishment or remanufacturing program in order to increase the circularity of their business model. Recent Miele product developments (i.e., their *"Twin Dos"* (Miele, 2017a) washing machine types with dedicated consumables in the form of detergent cartridges), however, indicate that Miele management have opted to move towards a Classic Long Life Hybrid model (see sub-section 4.7.1) instead of towards a Classic Long Life model with refurbishment and/or remanufacturing as a way of profiting more from the potential for longevity designed into their products.

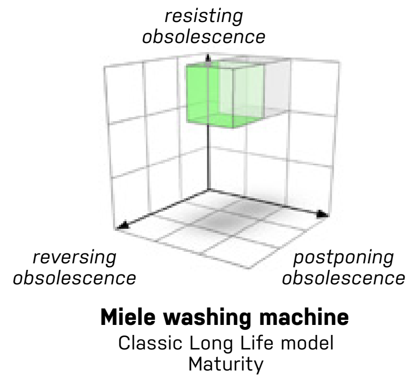


Figure 6.4.5: Comparison between predictions of the heuristic framework and existing Miele washing machine (detail taken from figure 6.4.4)

Taking into account the information from the company interviews (see section 5.5), our comparison shown in figure 6.4.4 also illustrates that in a situation where a product is part of several (circular) business model types, such as when circular business models are part of a

6

coordinated closed loop of multiple CBMs, in which each individual circular business model is responsible for its own specific part of the total closed loop (see section 4.4), it is important to carefully consider which (circular) business model type is used as a reference in the heuristic framework. In the instance of Océ for example, it is a strategic decision of Océ management not to handle the leasing of their products themselves but to transfer the ownership rights to their products to an independent leasing company instead. As can be seen in figure 6.4.6 however, the composition of design directions in the overall design intention for the Océ copier as assessed in chapter 3 differs from that predicted by the heuristic framework for a Classic Long Life model business model type but perfectly matches the composition as suggested by our heuristic framework if Océ would use an Access model instead of a Classic Long Life model.

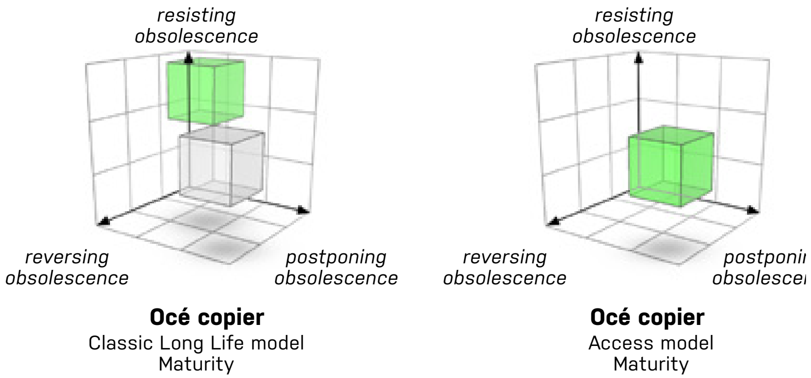


Figure 6.4.6: Comparison between predictions of the heuristic framework and existing Océ copier (detail taken from figure 6.4.4)

As such, Océ copiers appear to be designed more in line with what our heuristic framework would suggest based on the business model type that is used towards the end user than with what would be the suggestion based on the business model type that was selected by Océ management for use to its business-to-business customers.

The results from the comparison shown in figure 6.4.4 provide an indication of the potential usefulness of the newly proposed design method, but also highlight the limitations of the current version of the heuristic framework for design for managing obsolescence (that does for example not take into account the effects of product type) and thus the need for further empirical and theoretical research if managing obsolescence and the design method were to be made operational.

6.5 DISCUSSION AND CONCLUSIONS

This chapter set out to develop a design methodology for managing obsolescence. The objective of the chapter was to arrive at a set of design methods that could underpin product design for preserving product integrity through managing obsolescence in a circular economy, with tangible, durable consumer products as the focal point. As part of developing the design methodology, the chapter furthermore aimed to provide an answer to sub-research question E: "To what extent can some combinations of design interventions and business model types be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?"

A Design Methodology for Managing Obsolescence

In chapter 6, we presented four new design methods as part of a design methodology for managing obsolescence: (The development of) an obsolescence profile, (the development of) a longitudinal value proposition, (the development of) a longitudinal business model and a heuristic framework for managing obsolescence.

The purpose of the first design method we proposed in this chapter, i.e., (the development of) an obsolescence profile, is to enable industrial designers to generate and compare (a number of alternative) lifetime scenarios for a particular product designed for preserving product integrity. These scenarios, or obsolescence profiles, can provide the input that is needed for existing, scenario based, methods to calculate environmental consequences, such as LCA (Life Cycle Analysis) that can be used to quantitatively evaluate and compare alternatives.

The second design method we presented, i.e., (the development of) a longitudinal value proposition, concerns (the creation of) the value proposition(s) that are built around recovered presources at each moment along the obsolescence profile where recovered presources are reintroduced onto the market. The longitudinal value proposition describes the predetermined set of value propositions as required over a product's entire lifetime, i.e., along its obsolescence profile, in which changes in the properties of the tangible product along the obsolescence profile (i.e., as a result of interventions for preserving product integrity) are leveraged – or compensated for – by intangible aspects of the overall value proposition, such as changes in pricing and/or service levels. The design method of (developing) a longitudinal value proposition complements the design method of developing an obsolescence profile as it stresses that a specific value proposition is required for each specific transition along a product's obsolescence profile between product and presource (and vice versa) and offers a method for helping develop and describe these value propositions in advance.

The third design method that was introduced, i.e., (the development of) a longitudinal business model, is a logical consequence of the introduction of both the obsolescence profile and the longitudinal value proposition and concerns the support structure(s), i.e., the business model instance(s) for the longitudinal value proposition along the obsolescence profile. If the (outcome of) the interventions for preserving product integrity and the value proposition change along the obsolescence profile of a product, it is likely that the business model as a whole also has to also change along the obsolescence profile of a product, as it is the construct that supports and brings together the tangible and intangible components of the value proposition. The longitudinal business model is a description of the predetermined set and sequence of rationales of how an organisation creates, delivers and captures value that is required to support the longitudinal value proposition built around a product along the obsolescence profile of that product.
The three design methods are intended to be used together in an iterative process as part of the product innovation process in circular business models. Design for managing obsolescence thus involves the iterative and co-development of the tangible product, the obsolescence profile, the longitudinal value proposition and the longitudinal business model. As such, it follows that design for managing obsolescence requires industrial designers to work in close(r) collaboration with business professionals from other business functions that

6

are already more strategically involved, such as marketing. When managing obsolescence in absolute circular economy, it furthermore is the extent to which a potential for preserving product integrity that is designed and manufactured into a product can be realized, i.e., the extent to which the tangible product, the obsolescence profile, the longitudinal value proposition and the longitudinal business model are a match, that determines the amount of value that can be created and captured. As such, with design for managing obsolescence, industrial design could well become a factor in developing business strategy instead of being determined by business strategy (much in the same way as what happened to marketing with the introduction of relationship marketing (see Appendix C: The Strategy Concept: Definition, Evolution and Ontology)).

The application of the above three design methods requires industrial designers (and other business professionals) to make complex and often interrelated decisions, many of which can be based only on assumptions with regard to future developments. The developments that have to be taken into account when designing for managing obsolescence differ from those that are performed in the context of linear business models of the Sell More, Sell Faster type in that they tend to stretch further into the future, and more often than not involve multiple use cycles, potentially by different users and in the context of different business model types. Because of this, design for managing obsolescence, on top of the normal challenges posed by the product innovation processes as they are performed in the context of a linear economy, provides at least two additional challenges that are new to industrial designers: To design in the *temporal* dimension as well as in the spatial dimension, and to consider and decide on design interventions for preserving product integrity *in conjunction with circular business model types*. Although the present literature on (sustainable) product design contains design methods to help industrial designers decide on (the order of) design interventions from an environmental perspective when designing for managing obsolescence, it does not provide a design method that provides guidance to industrial designers (and other business professionals) in selecting (design) interventions in conjunction with circular business model types. We therefore proposed a fourth design method intended to contribute to filling this gap in the current literature and to provide guidance to industrial designers in selecting successful combinations of design directions and circular business model types.

Our review of the current literature on (sustainable) product design and PSS-based business model types made clear that the extent to which design directions can be expected to be successful when used in conjunction with a particular circular business model type depends on product type and life cycle stage pertaining to the particular product (see figure 6.4.1). The extant literature on (sustainable) product design and PSS-based business model types, however, is inconclusive with regard to (the extent to) which combinations of design directions (for preserving product integrity) and PSS-based business model types are successful and as such could not provide us with an answer to sub-research question E.
For lack of theoretical foundation and empirical data in the literature on (sustainable) product design and PSS-base business models to use as a foundation for the development of a design method to provide guidance to industrial designers in selecting design directions and circular business model types, we decided to expand our literature review into the literature in product life cycle theory and to present our fourth design method as a conceptual proposition in the form of a set of design heuristics, i.e., "*rules of thumb*" (Lawson, 1980, p. 132) "*linking the designer to a broad range of helpful guidance*" (Yilmaz et al, 2016, p. 96). Although, because of their nature, design heuristics may not always directly lead to the most optimal solution (Yilmaz et al., 2016, referencing Nisbett & Ross, 1980), their primary usefulness resides in that they provide sensible starting points in the search for viable solutions and "*can help designers generate more, and more varied, candidate concepts to consider in the early phases of design*" (Yilmaz et al., 2016, p. 95). The design method that we presented here, i.e., a *heuristic framework for design for managing obsolescence*, is constructed from a set of inferences with regard to the extent to which design directions for preserving product integrity can be expected to be successful when used in conjunction with specific circular business model types for preserving product integrity. These inferences are the result of careful reflection in light of the secondary data and the industry knowledge acquired by the author in over 20 years of practice as an industrial designer.

We acknowledge that, as such, the newly proposed heuristic framework for design for managing obsolescence at present lacks – and therefore is in need of future – theoretical and empirical validation, however, we consider these tasks to lie outside the scope of the present thesis.

The heuristic framework for design for managing obsolescence as presented in figure 6.4.3 provides an overview of the extent to which particular combinations of design directions and circular business model types for preserving product integrity can be expected to be successful in different stages of the product category life cycle. It has been populated with the expectations of success for various combinations of design directions for preserving product integrity and circular business model types for preserving product integrity based on the inferences mentioned above. For the development of the heuristic framework for design managing obsolescence we have considered life cycle theory from the product life cycle (instead of the technology lifecycle) perspective at the aggregation level of product (sub-) category. Sood et al. (2012), however, have argued that, with regard to predicting the course of technological innovation over time, many of the often used and popular models in life cycle theory "*are naïve generalizations of what seems to be a complex phenomenon*" (p. 977) and proposed for example the "*SAW*" (p. 969) (the acronym stands for "Step And Wait") model as a more accurate predictive approach. This may well be a valid argument, and approaches like SAW (Sood et al, 2012) may help to refine and improve the predictive quality of the heuristic framework for design managing obsolescence as currently proposed. However, at present the literature does not provide examples that connect technology lifecycle-based approaches like SAW (Sood et al., 2012) to design directions or PSS-based business model types at a type level.

The literature (see sub-section 6.4.1) furthermore indicates that the suggestions as to which combinations can be expected to be successful as indicated by the heuristic framework could be different for different product types, as the product type affects both the extent to which particular combinations of PSS-based business model types and the extent to which individual design directions can be expected to be successful (see figure 6.4.1). However, as the literature does not provide data as to 1) which product classification system to use and 2) how the range of different product types from a particular classification scheme affect the extent to which combinations of design directions and circular business model types can be expected to be successful, the heuristic framework for design for managing obsolescence as presented here is not differentiated by product type.

6

Additionally, our heuristic framework for design for managing obsolescence must perhaps be expanded further to accommodate even finer gradations. In one of the explorative conversations in order to select companies for the company interviews, we learned from Mark Schrooten, at the time of the conversation (July 30th, 2013) Innovation Director at a company named Dorel (Dorel, 2018) –- that in the end did not become one of the companies that were formally interviewed for this research – that even within a single product (sub-) category such as baby strollers, the extent to which combinations of design directions and circular business models can be expected to be successful can differ as a result of differences that have their origin in culture and/or market geography. In some Southern European countries for example, baby strollers must be brand-new as previously used ones are culturally not acceptable. When a particular product is traded locally as well as exported to far away countries, it often is a good idea to design the product in such a way that it is optimally suited to be traded both as part of a Classic Long Life model type (i.e., export market with limited or no service organization) *and* as part of an Access model type (local market and local service organization).

We acknowledge that our conceptual proposition for the heuristic framework for design for managing obsolescence presented here does not reflect product type and/or culture and market geography dependent findings like the ones discussed above. As a consequence, it should therefore be considered generic and recognized as having limited predictive value. From our perspective, the predictive value of the version of the heuristic framework as presented here, however, is secondary. We consider the primary purpose of the heuristic framework for design for managing obsolescence as presented here to be twofold. Firstly, it serves to illustrate how we envision a method for design for managing obsolescence that integrally captures and communicates the varying extent to which different combinations of design directions and circular business model types can be expected to be successful as a result of different product types, life cycle stages and circular business model types. A design method that is aimed at providing guidance to industrial designers (and other business professionals) in selecting design directions and circular business model types when designing for managing obsolescence. Secondly, it highlights a gap in the literature with regard to the extent to which a combination of design directions and circular business models can be expected to be successful. As such, it indicates the need for further research should there be a desire to make the concept of managing obsolescence and the design methodology for managing obsolescence operational as part of (the transition to) an absolute circular economy.

Perhaps one of the most important insights gained in this chapter, however, is that managing obsolescence should not be considered a *one-size-fits-all* approach, but that (design for) managing obsolescence instead requires the development of *tailor-made* solutions, that take into careful consideration factors like product type, product (sub-)category lifecycle stage, circular business model types as can be – as conceptual proposition currently presented does not take into account product type – expressed in the method of the heuristic framework for design for managing obsolescence. Initial directions can then be fine-tuned to accommodate cultural preferences and integrate managerial (e.g., strategic) considerations over the entire product lifetime in order to be successful. Although the current literature provides some indications of, and allows for interferences as to, the extent to which these factors can cause certain combinations of design directions and circular business model types to be more successful than others, it is largely inconclusive and further research is necessary to capture and assess the nature of the relationships in greater detail.

The design methodology as presented in this chapter offers methods to industrial designers that are intended to help them work with the above factors, get a grip on their effects on and requirements for the design of the tangible product and develop such tailor-made solutions. However, as the design methodology of design for managing obsolescence was developed *based upon theory* and has not been tested or validated empirically it is in need of future validation before it could be made operational.

REFERENCES CHAPTER 6: A DESIGN METHODOLOGY FOR MANAGING OBSOLESCENCE

Abell, D.F. (1980). *Defining the Business: The Starting Point of Strategic Planning*. Englewood Cliffs, NJ, USA: Prentice Hall, Inc.

Abernathy W. J., & Utterback J. M. (1978). Patterns of Innovation in Technology. *Technology Review 80*, 40-47.

Anderson, C. (2008). *The Long tail: Why the future of business is selling less of more.* Hyperion.

Anderson, P., & Tushman, M. L. (1990). Technological discontinuities and dominant designs: A cyclical model of technological change. *Administrative science quarterly*, 604-633.

Antikainen, M., Lammi, M., Paloheimo, H., Rüppel, T., & Valkokari, K. (2015, December). Towards Circular Economy Business Models: Consumer Acceptance of Novel Services. In *ISPIM Innovation Symposium* (p. 1). The International Society for Professional Innovation Management (ISPIM).

Armstrong, C. M., Niinimäki, K., Kujala, S., Karell, E., & Lang, C. (2015). Sustainable product-service systems for clothing: exploring consumer perceptions of consumption alternatives in Finland. *Journal of Cleaner Production*, *97*, 30-39.

Atasu, A., Guide Jr., V. D. R., & Van Wassenhove, L. N. (2008). Product Reuse Economics in Closed-Loop Supply Chain Research. *Production and Operations Management 17*(5), 483-496.

Aurich, J.C., Fuchs, C., & Wagenknecht, C. (2006). Life cycle oriented design of technical Product-Service Systems. *Journal of Cleaner Production, 14*(17), 1480-1494.

Azarenko, A., Roy, R., Shehab, E., & Tiwari, A., (2009). Technical product-service systems: some implications for the machine tool industry. *Journal of Manufacturing Technology Management 20*(5), 700-722.

Bakker, C.A., Den Hollander, M.C., Van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. TU Delft Library/Marcel den Hollander IDCR

Bakker, C.A., Wang, F., Huisman, J., & Den Hollander, M.C. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production 69*, 10-16.

Bartels, B., Ermel, U., Sandborn, P., Pecht, M. (2012). *Strategies to the Prediction, Mitigation and Management of Product Obsolescence*. Hoboken, NJ, USA: John Wiley & Sons Inc.

Bjørn, A., & Hauschild, M. Z. (2012). Absolute versus relative environmental sustainability. Journal of Industrial Ecology, *17*(2), 321-332.

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van der Grinten, B. (2016). Product design and business model strategies for a circular economy, *Journal of Industrial and Production Engineering, 33*(5), 308-320.

Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, *45*, 9-19.

Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. *British journal of management*, *11*(1), 1-15.

Buschmann, F. (2010). Learning from failure, part 2: featuritis, performitis, and other diseases. *IEEE software*, *27*(1).

Buzzell, R. (1966). Competitive Behavior and Product Life Cycles. In Wright, J. & Goldstucker, J. (Eds.), *New Ideas for Successful Marketing*. Chicago, IL, USA: American Marketing Association.

Capon, N. (1985). *The Product Life Cycle*. Document 9-579-072. Harvard, U.S.A.: Harvard Business School.

Casadesus-Masanell, R., & Ricart, J. E. (2010). From strategy to business models and onto tactics. *Long Range Planning, 43*, 195-215.

Copeland, M. T. (1923). Relation of consumers' buying habits to marketing methods. *Harvard business review, 1*(3), 282-289.

Cusumano, M. A., Kahl, S. J., & Suarez, F. F. (2015). Services, industry evolution, and the competitive strategies of product firms. *Strategic Management Journal, 36*(4), 559-575.

Darby, M. R., & Karni, E. (1973). Free competition and the optimal amount of fraud. *The Journal of law and economics, 16*(1), 67-88.

Dhalla, N. K., & Yuspeh, S. (1976). Forget the Product Life Cycle Concept. Retrieved January 20th, 2018 from: https://hbr.org/1976/01/forget-the-product-life-cycle-concept. (PDF web reprint from *Harvard Business Review, 54*, 102–112).
De los Rios, I. C., & Charnley, F. J. (2017). Skills and capabilities for a sustainable and circular economy: The changing role of design. *Journal of Cleaner Production, 160*, 109-122.
De Pauw, I. C. (2015). *Nature-Inspired Design: Strategies for Sustainable Product Development* (Doctoral dissertation, Delft University of Technology, Delft, the Netherlands).
Dorel (2018). Dorel company website. Retrieved January 12th, 2017 from: http://www.dorel.com/eng/.
Eger, A.O., & Drukker, J.W. (2010). Phases of Product Development: A Qualitative Complement to the Product Life Cycle. *Design Issues 26*(2), 47-58.
Erler, S., & Rieger, E. (2016). Product Evolvement through Entirely Scheduled Lifecycles. *Procedia CIRP*, *48*, 79-83.
Europa (2017). *Guarantees and returns.* Retrieved November 26th, 2017, from http://europa.eu/youreurope/citizens/consumers/shopping/guarantees-returns/index_en.htm.
Evans, S., Partidário, P. J., & Lambert, J. (2007). Industrialization as a key element of sustainable product-service solutions. *International Journal of Production Research*, *45*(18-19), 4225-4246.
Fang, E., Palmatier, R. W., & Steenkamp, J. B. E. (2008). Effect of service transition strategies on firm value. *Journal of Marketing*, *72*(5), 1-14.
Frambach, R. T., Wels-Lips, I., & Guendlach, A. (1997). Proactive product service strategies: an application in the European health market. *Industrial Marketing Management*, *26*(4), 341-352.
Gebauer, H., Joncourt, S., & Saul, C. (2016). Services in product-oriented companies: past, present, and future. *Universia Business Review*, 49, 32-53.
Gaiardelli, P., Resta, B., Martinez, V., Pinto, R., Albores, P. (2014). A classification model for Product-Service offerings. *Journal of Cleaner Production, 66*, 507-519.
Golder, P. N. & Tellis, G. J. (2004). Growing, Growing, Gone: Cascades, Diffusion, and Turning Points in the Product Life Cycle. Marketing Science, 23(2), 207-218.
Gruber, T.R. (1993). A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition, 5*(2), 199-220.
Hagen-Zanker, J., & Mallett, R. (2013). *How to do a rigorous, evidence-focused literature review in international development, A Guidance Note.* London: Overseas Development Institute.
Hamermesh, R. E., & Silk, S. B. (1979). How to Compete in Stagnant Industries. Retrieved November 26th, 2017 from https://hbr.org/1979/09/how-to-compete-in-stagnant-industries (PDF web reprint from *Harvard Business Review, 57*(5), pp. 161-168.
Harrigan, K. R., & Porter, M. E. (1983). End-Game Strategies for Declining Industries. Harvard Business Review, Vol. 61, No. 4, pp. 111-120.
Hart, C. (2011). *Doing a literature review: Releasing the social science research imagination.* London, UK: SAGE.
Herman, S. (1981). The uses and abuses of Roman law texts. *The American Journal of Comparative Law*, *29*(4), 671-690.
Hirschman, E. C., & Holbrook, M. B. (1982). Hedonic consumption: emerging concepts, methods and propositions. *The Journal of* Marketing*, 46*(3), 92-101.
Hofer C. (1975). Toward a Contingency Theory of Business Strategy. *The Academy of Management Journal, 18*(4), 784-810
ISO (2006). *ISO 14040: 2006. Environmental management – life cycle assessment– principles and framework.* International Standardization Organisation.
Kim, B. (2003). Managing the transition of technology life cycle. *Technovation, 23*, 371–381.
Kotler, P. (1984). *Marketing Management* (5th ed.), London, UK: Prentice/Hall International.
Kuo, T.C. (2011). Simulation of purchase or rental decision-making based on product service system. *International Journal of Advanced Manufacturing Technology, 52(9),* 1239-1249.
Lawson, B. (1980). *How Designers Think: The Design Process Demystified.* London, UK: Architectural.
Levitt, T. (1965). Exploit the product life cycle. Retrieved November 26th, 2017 from https://hbr.org/1965/11/exploit-the-product-life-cycle (PDF web reprint from *Harvard business review*, *43*, 81-94).
Malone, T. W., Weill, P., Lai, R. K., D'Urso, V. T., Herman, G., Apel, T. G., & Woerner, S. (2006). *Do some business models perform better than others*? Retrieved November 20th, 2017 from https://mpra.ub.uni-muenchen.de/4751/1/MPRA_paper_4751.pdf.
Mason, R. (2005). Missing links: Product classification theory and the social characteristics of goods. *Marketing theory, 5*(3), 309-322.
Meier, H., Roy, R., Seliger, G., (2010). Industrial Product-Service Systems IPS2. CIRP Ann. 59 (2), 607-627.
Mont, O., Dalhammar, C., & Jacobsson, N. (2006). A new business model for baby prams based on leasing and product remanufacturing. *Journal of Cleaner Production*, *14*(17), 1509-1518.
Moogk, D. R. (2012). *Minimum viable product and the importance of experimentation in technology startups*. Technology Innovation Management Review, 2(3), 23.
Moon, Y. (2005). Break Free from the Product Life Cycle. Retrieved December 20th, 2017 from: https://hbr.org/2005/05/break-free-from-the-product-life-cycle (PDF web reprint from *Harvard Business Review, 83*(5), 86-94). *Harvard Business Review*, May issue.
Moss, M. A. (1985). *Designing for minimal maintenance expense: The practical application of reliability and maintainability*. Quality and Reliability series part 1. New York, NY, USA: Marcel Dekker.
Mugge, R. (2007). *Product Attachment* (Doctoral thesis). Delft University of Technology, Delft, the Netherlands.
Murphy, P. E., & Enis, B. M. (1986). Classifying products strategically. *The Journal of Marketing*, *50*(3), 24-42.
Neely, A., (2009). Exploring the financial consequences of the servitization of manufacturing. *Operation Management Research*, 1(2), 103-118.
Nelson, P. (1970). Information and consumer behavior. *Journal of political economy*, *78*(2), 311-329.
Nisbett, R. E., & Ross, L. (1980). *Human Inference: Strategies, and Shortcomings of Social Judgment*. Englewood Cliffs, NJ, USA: Prentice-Hall.
Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation*. Hoboken, NJ, USA: John Wiley & Sons.
Peres, R., Muller, E., & Mahajan, V. (2009). Innovation diffusion and new product growth models: A critical review and research directions. *International Journal of Research in Marketing, 27*, 91-106.
Polli, R., & Cook, V. (1969). Validity of the product life cycle. *The Journal of Business, 42*(4), 385-400.
Reim, W., Parida, V. & Örtqvist, D. (2015). Product-Service Systems (PSS) business models and tactics - a systematic literature review. *Journal of Cleaner Production, 97*, 61-75.
Richins, M. L., & Bloch, P. H. (1986). After the new wears off: The temporal context of product involvement. *Journal of Consumer research*, *13*(2), 280-285.
Ries, E. (2009). *Minimum Viable Product: a guide.* Retrieved January 9th, 2017 from: http://soloway.pbworks.com/w/file/fetch/85897603/1%2B%20Lessons%20Learned_%20Minimum%20Viable%20Product_%20a%20guide2.pdf.
Ries, E. (2011). *The Lean Startup* (Kindle ed.). New York, NY, USA: Crown Business.
Rink, D. R., & Swan, J. E. (1979). Product life cycle research: A literature review. *Journal of business Research, 7*(3), 219-242.
Rogers, E.M., (2003). *Diffusion of Innovations* (5th ed.) New York, U.S.A.: The Free Press.
Rose, C. M. (2000). *Design for environment: a method for formulating product end-of-life strategies* (Vol. 185). Stanford, CA, USA: Stanford University.
Rose, C.M., & Ishii, K. (1999). Product end-of-Life strategy categorization design tool. *Journal of Electronics Manufacturing, 9*(01), 41-51.
Saxena, K. B. C., Deodhar, S. J., & Ruohonen, M. (2017). The Business Model Concept and its Use. In *Business Models Innovation in Software Product Industry, 13-34*. India: Springer India.
Schridde, S. (2014). *Murks? Nein danke!* München, Germany: Oekom Verlag.
Simon, H.A., & Newell, A. (1958). Heuristic Problem Solving: The Next Advance in Operations Research. *Operations Research 6*(1), 1-10.
Sood, A., James, G. M., Tellis, G. J., & Zhu, J. (2012). Predicting the path of technological innovation: SAW vs. Moore, Bass, Gompertz, and Kryder. *Marketing Science, 31*(6), 964-979.
Sood, A. & Tellis, G.J. (2005). Technological Evolution and Radical Innovation. *The Journal of Marketing, 69*(3), 152-168.
Stevels, A. L. N. (2007). *Adventures in EcoDesign of Electronic Products 1993-2007*. Delft, the Netherlands: Delft University of Technology, Faculty of Industrial Design Engineering.
Suarez, F. F., Cusumano, M. A., & Kahl, S. J. (2013). Services and the business models of product firms: an empirical analysis of the software industry. *Management Science*, *59*(2), 420-435.
Sundin, E., & Bras, B. (2005). Making functional sales environmentally and economically beneficial through product remanufacturing. *Journal of Cleaner Production, 13(9),* 913-925.
Taylor, M., & Taylor, A. (2012). The technology life cycle: Conceptualization and managerial implications. *International journal of production economics*, *140*(1), 541-553.
Tellis, G., & Crawford, C.M. (1981). An Evolutionary Approach to Product Growth Theory. *The Journal of Marketing, 45*(4), 125-132.
Tischner, U., Schminke, E., Rubik, F., & Prösler, M. (2000). *How to do EcoDesign? A guide for environmentally and economically sound Design.* In collaboration with B. Dietz, S. Maßelter & B. Hirschl, edited by the German Federal Environmental Agency. Frankfurt am Main, Germany: Verlag form Praxis.
Tukker, A. (2004). Eight Types of Product– Service System: Eight Ways to Sustainability? Experiences from Suspronet. *Business Strategy and the Environment 13*, 246–260.
Tukker, A. (2015). Product services for a resource-efficient and circular economy - a review. *Journal of Cleaner Production, 97*, 76-91.
Tukker, A., Van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In A. Tukker and U Tischner (Eds.), N*ew Business for Old Europe - Product-service development, competitiveness and sustainability* (pp. 22-34). Sheffield, UK: Greenleaf Publishing Ltd.

Ulaga, W., & Reinartz, W.J. (2011). Hybrid offerings: how manufacturing firms combine goods and services successfully. Journal of Marketing, 75(6), 5-23.
White, G. R. (1979). Management criteria for effective innovation. *IEEE Transactions on Professional Communication*, (2), 77-82.
Williams, A., (2007). Product service systems in the automobile industry: contribution to system innovation? *Journal of Cleaner Production, 15*(11-12), 1093-1103.
Windrum, P., & Birchenhall, C. (1998). Is product life cycle theory a special case? Dominant designs and the emergence of market niches through coevolutionary-learning. *Structural Change and Economic Dynamics*, *9*(1), 109-134.
WIPO (World Intellectual Property Organization) (2017). NICE Classification of goods and services (11th ed.). Retrieved January 4th, 2018 from: http://www.wipo.int/classifications/nice/en/.
Wirtz, B.W., Pistoia, A., Ullrich, S., & Göttel, V. (2016). Business Models: Origin, Development and Future Research Perspectives. *Long Range Planning 49*, 36-54.
Xing, K., Luong, L., & Abhary, K. (2005). A methodical planning to enhance reutilisation potential in product design. In *Proceedings of AGEC 2005, International Conference on Asian Green Electronics*, 59-66.
Yilmaz, S., Daly, S. R., Seifert, C. M., & Gonzalez, R. (2016). Evidence-based design heuristics for idea generation. *Design Studies, 46*, 95-124.

6

7

CONCLUSIONS AND RECOMMENDATIONS

What design methodology can help and enable industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?

7.1 INTRODUCTION

The end goal of this thesis was to develop a new design methodology that can help industrial designers to design products with a long or extended lifetime in support of a circular economy, i.e., identify and develop guiding principles, design strategies and design methods to underpin tangible product design for long and extended lifetimes in a circular economy.

The aim of a circular economy is to limit the flows of materials and energy into and out of the economic system at levels that in principle can be tolerated and sustained indefinitely by nature whilst protecting the capacity of the economic system to create wealth (Korhonen et al., 2018). In a circular economy, the economic and environmental value of materials is preserved by keeping them in the economic system for as long as possible, preferably by lengthening the useful lifetimes of products formed from them and, when lifetime extension at product level is no longer possible for environmental or economic reasons, by looping products back into the manufacturing process so their constituent materials can be reused. The notion of *waste* no longer exists in a circular economy because products and materials are, in principle, reused and cycled indefinitely. It follows that product lifetime extension – not instead of but in addition to materials recycling – and the ability to create, deliver and capture economic value from long or extended product lifetimes are essential to a circular economy. Industrial design has the potential to contribute significantly to achieving the goals of a circular economy (SER, 2016; EC, 2015a; EPEA, 2004), because the design of a product directly affects the characteristics of the physical product as well as the structure of the entire value chain (De los Rios & Charnley, 2016).

The thesis adopted an interpretation of the circular economy concept that is based on material flow concepts developed in the field of industrial ecology (Ayres, 1994; Stahel, 1994, 2010; Lifset & Graedel, 2002): The intention of a circular economy from a material flows perspective is to work toward a closed loop economic system that mimics the *"cyclic materials flow of* [a] *'type III' ecology"* (Lifset & Graedel, 2002, p. 5; Graedel & Allenby, 2003) as closely as possible (WRAP, 2017; Bocken et al., 2016; EMF, 2015; 2014; 2013; 2012), acknowledging that, in practice, there will always be a certain amount of unavoidable dissipation (Ciacci et al., 2015). Based on the above interpretation of the circular economy concept as an *absolute* approach to sustainability (De Pauw, 2015; Faber et al., 2005), the thesis took as its starting point that eco-design (i.e., a *relative* approach to sustainability (De Pauw, 2015; Faber et al., 2005) and circular product design differ on a fundamental level and that this will impact the design methods used by industrial designers. In addition, the thesis worked from the premise that industrial design is driven by business objectives.

The thesis therefore started its investigation with the main research question below:

"What design methodology can help and enable industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?"

To arrive at an answer to the main research question, this thesis systematically addressed the following sub-research questions in the order they are presented below, whereby the answers to sub-research questions A, B and C provided the requisite theoretical framework for addressing sub-research questions D and E:

A: "How can product lifetime extension in a circular economy be defined within the context of industrial design?"

B: "What guiding principles and design interventions can industrial designers use when designing for long and extended product lifetimes in a circular economy?"

C: "What business model types can companies use to create, deliver and capture value from long and extended product lifetimes in a circular economy?"

D: "What guiding principles and management strategies can businesses use when creating, delivering and capturing value from long and extended product lifetimes in a circular economy?"

E: "To what extent can some combinations of design interventions and business model types be expected to be more successful in creating, delivering and capturing value from long and extended product lifetimes in a circular economy than others?"

Chapter 7 begins with the presentation of the main conclusion of the study in answer to the main research question. Section 7.2 then presents the findings that have led to and support this main conclusion in the order of the sub-research questions that yielded them. Limitations of the study and recommendations for further research are discussed next in section 7.3. Section 7.4 discusses the implications for industrial designers, business professionals and policy makers that follow from the main conclusions. Finally, section 7.5 provides the closing remarks for this chapter and the thesis.

7.2 MAIN CONCLUSIONS

In answer to the main research question – "what design methodology can help industrial designers to design products that are tailored to match business model types for creating, delivering and capturing value from long and extended product lifetimes in a circular economy?" – this thesis argues that in order to increase the likelihood that product lifetime extension in a circular economy will be successful from both an environmental and an economic perspective, industrial designers need to be able to control not only the spatial dimension (materialization and geometry) of products, but also the *temporal* dimension. This temporal dimension is related to the number and duration of product use cycles and the duration of total product lifetime. To enable industrial designers to capture this temporal dimension, the thesis presented:

- a new design methodology: design for managing obsolescence;
- five new design methods and two typologies in support of managing obsolescence;
- insight into (the factors determining) how and when to best apply these methods;
- insight into where and in collaboration with whom to apply these methods in the product innovation process.

7.2.1 A New Design Methodology for Managing Obsolescence

The design methodology for managing obsolescence introduced in this thesis allows industrial designers, in close collaboration with professionals from other business functions such as marketing, engineering and production, to predetermine, control and communicate the point(s) in time when a product will become obsolete. The purpose of the business practice of managing obsolescence is to enhance the economic and environmental efficiency of recovery processes in order to maximize the total lifetime (including lifetime extensions) of a product in a circular economy. The essence of managing obsolescence lies in the fact that successfully preserving product integrity is not achieved by preserving functionality over time (i.e., a tangible product design and engineering task) but instead relies on preserving perceived value over time (i.e., a combined task of tangible product design and engineering and the marketing function).

The design methodology for managing obsolescence was developed based on the introduction and redefinition of a set of key concepts and terms relating to (design for) product lifetime extension in a circular economy. For example, the thesis redefined the concepts of circular business model, business model circularity and interventions for preserving product integrity, such as maintaining, updating, repairing, recontextualizing, refurbishing and remanufacturing. Examples of some of the newly introduced terms and concepts are presource, recovery horizon and leakage.

Fundamental to the thesis were the absolute perspective on sustainability taken in considering the circular economy, the introduction of the new concept of product integrity and the redefinition of the concept of product lifetime in terms of *obsolescence* rather than functionality (as hitherto has been common in the current literature). Building on Stahel's (2010) Inertia Principle, the thesis defined the concept of product integrity as the extent to which a product remains identical to its original (e.g., as manufactured) state. Considering the circular economy from an absolute perspective on sustainability removed the option of expelling unwanted products and/or materials from the economic system as waste and created a context for the research in which product lifetime extension and the preservation of added economic value were mandatory. In this absolute context, the *order* in which interventions for product lifetime extension are performed becomes essential for preserving as much added economic value as possible. With the newly introduced concept of product integrity, the thesis provided a basis for determining the preferred order of interventions. By defining product lifetime in terms of obsolescence, the thesis acknowledged the findings from both the literature and the company interviews that product lifetime is not merely an engineering quality to be designed into a product, but rather is highly subjective and affected by a host of factors other than the design of the tangible product, including user behaviour and the product's wider socio-economic context (Cooper, 2010).

7.2.2 Five New Design Methods and Two Typologies in Support of Managing Obsolescence

The design methodology of managing obsolescence offers five new design methods (Daalhuizen, 2014) to assist industrial designers in designing long-life products for a circular economy: 1) the three-dimensional design space for preserving product integrity, 2) (the development of) the obsolescence profile, 3) (the development of) the longitudinal value proposition, 4) the (development of) the longitudinal business model and 5) the heuristic framework for design for managing obsolescence.

The above methods are in turn supported by two newly developed typologies that provide industrial designers with options to choose from when creating obsolescence profiles, longitudinal value propositions and longitudinal business models. The first new typology is comprised of eight design strategies for preserving product integrity that are categorized into three different types, i.e., design strategies for resisting obsolescence, for postponing

7

obsolescence and for reversing obsolescence. The second new typology consists of three different circular business models for preserving product integrity, i.e., the product-oriented Classic Long Life model, the use-oriented Access model and the result-oriented Performance model.

The Three-Dimensional Design Space for Preserving Product Integrity
The three-dimensional design space for preserving product integrity is a visual representation of the relative importance of the three main design directions for preserving product integrity (i.e., resisting obsolescence, postponing obsolescence and reversing obsolescence) within the overall design intention for products tailored to circular business models for preserving product integrity. It is intended help industrial designers to capture and better understand the potential for preserving product integrity as it was (or is to be) designed into a particular product. The three-dimensional design space for preserving product integrity provides industrial designers with a means to compare (and learn from) design intentions for different products, to recognize differences in emphasis on the various design directions between different (existing) products and to help steer the selection and interpretation of design principles for a particular product. An illustration of the three-dimensional design space for preserving product integrity shown in figure 7.2.1.

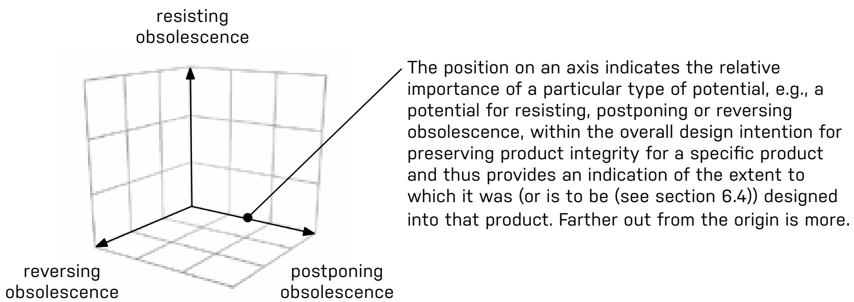


Figure 7.2.1: The three-dimensional representation of the design space for preserving product integrity.

The Obsolescence Profile, the Longitudinal Value Proposition and the Longitudinal Business Model
The obsolescence profile for a product describes the predetermined sequence covering the entire lifetime of a product that lists the point(s) in time when, and the way(s) in which, a product will be prevented from becoming obsolete and/or will become obsolete and subsequently will be recovered. As such, it captures the predetermined series of use cycles (e.g., number and duration) of a product that would enable a circular business model for preserving product integrity to maximize business model circularity (defined by the thesis as the fraction of economic value added to (p)resources that is preserved over time) for this product. As the properties of the product can, however, vary between use cycles (e.g., a refurbished product is different from a new product), the contribution of the tangible product to the overall value proposition it is embedded in is likely to differ accordingly. For example, whereas a new smartphone can be offered as part of a premium priced service plan, a refurbished phone would most likely require a service plan with discounted rates to result in an attractive and viable value proposition.

The longitudinal value proposition describes the predetermined set of value propositions in which changes in the properties of the tangible product along the obsolescence profile are compensated by, for example, changes in pricing and/or service levels as required over a product's entire lifetime, i.e., along its obsolescence profile.

The longitudinal business model describes the predetermined set of business models that matches the longitudinal value proposition along the obsolescence profile, as in some instances the different value propositions need different business models to support them (e.g., different channels, different key partners).

A Heuristic Framework for Design for Managing Obsolescence: Guidance as to When Best to Apply What
To aid industrial designers in meeting the new challenges posed by designing for managing obsolescence in a circular economy (i.e., designing in the *temporal* dimension as well as in the spatial dimension and selecting design directions in conjunction with circular business models for preserving product integrity), the thesis developed and presented a heuristic framework for design for managing obsolescence. The heuristic framework for design for managing obsolescence is intended to provide guidance to industrial designers (and other business professionals) in selecting design directions and circular business model types for preserving product integrity when developing obsolescence profiles, longitudinal value propositions and longitudinal business models.

Design heuristics are "*mental shortcuts"* (Yilmaz et al., 2016, p. 96) that *"do not so much rely upon theoretical first principles as on experience and rules of thumb"* (Lawson, 1980, p. 132). They capture *"patterns common in successful design solutions ... linking the designer to a broad range of helpful guidance from past solutions in a refined form*" (Yilmaz et al, 2016, p. 96). Because of their nature, design heuristics may not always directly lead to the most optimal solution (Yilmaz et al., 2016, referencing Nisbett & Ross, 1980). Their primary usefulness resides in that they provide sensible starting points in the search for viable solutions and *"can help designers generate more, and more varied, candidate concepts to consider in the early phases of design"* (Yilmaz et al., 2016, p. 95).

A visual representation of the heuristic framework for design for managing obsolescence is shown in figure 7.2.2.

The colours of the cubes represent the extent to which a particular circular business model type can be expected to realize a potential for preserving product integrity that was designed (and manufactured) into a product. The positions of the cubes on the axes indicate the relative importance of a particular type of potential, e.g., a potential for resisting, postponing or reversing obsolescence, within the overall design intention for preserving product integrity for a specific product and thus provides an indication of the extent to which it was (or is to be (see section 6.4)) designed into that product. Farther out from the origin is more. For lack of theoretical and empirically validated data in the extant literature as to which particular combinations of design directions and PSS-based (circular) business model types are successful, the heuristic framework was constructed from inferences. Although these inferences are the result of careful reflection in the light of the secondary data and the authors' 20 years industry knowledge, they are made on the basis of incomplete (e.g. not taking into account the effects of product type) and non-validated information. Therefore, the heuristic framework is presented here as a conceptual proposition. As a consequence, the version of the frame-

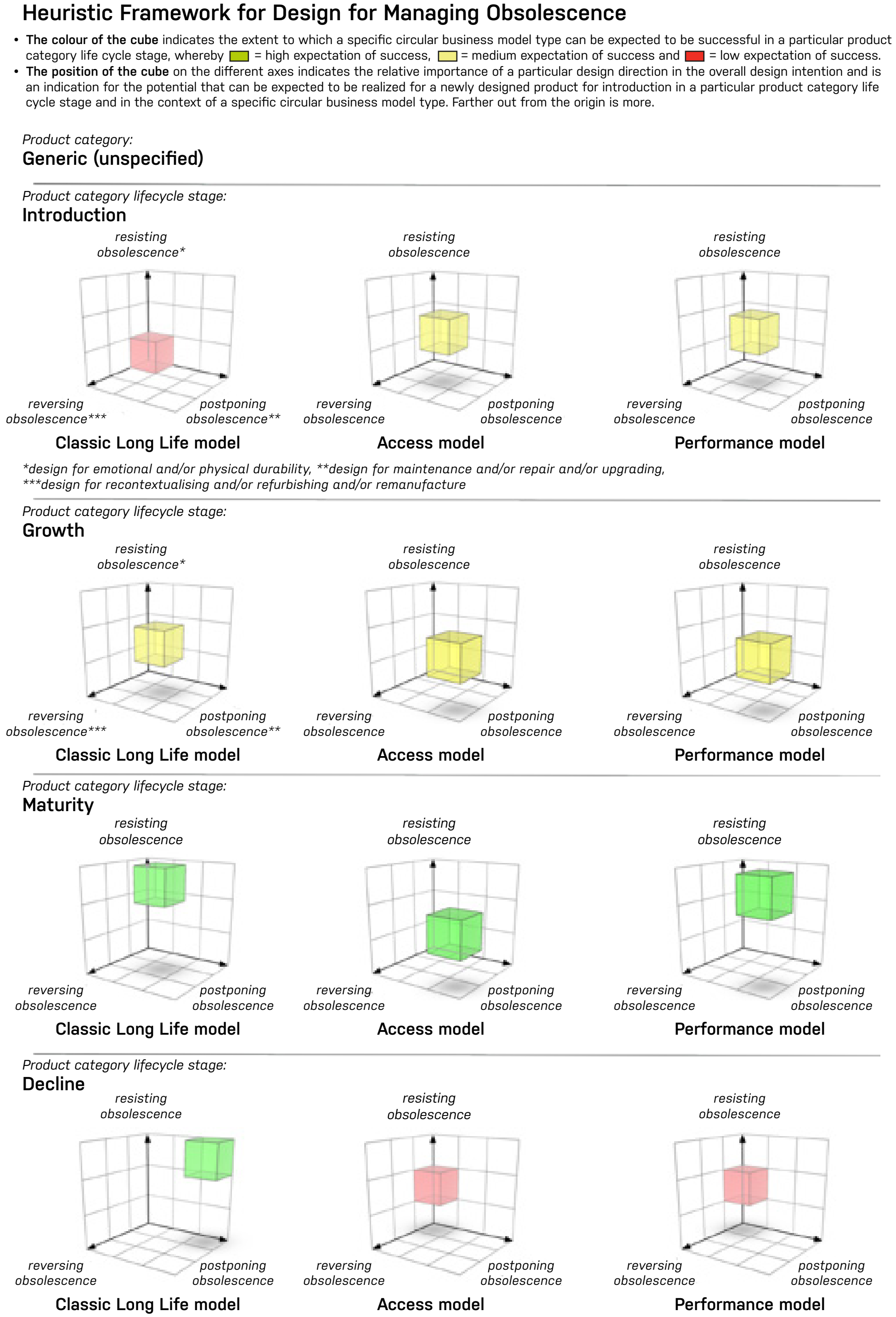


Figure 7.2.2: A heuristic framework for design for managing obsolescence based on the inferences presented in sub-section 6.4.2.

work presented here should be considered generic and recognized as having limited predictive value. A comparison between the predictions for successful combinations of design directions and circular business models from the heuristic framework and those found in twelve existing products for example, yielded perfect and close matches as well as some discrepancies. From our perspective, the predictive value of the heuristic framework as presented here, however, is secondary. We consider the primary purpose of the heuristic framework for design for managing obsolescence as presented here to be twofold. Firstly, it serves to illustrate how we envision a method for design for managing obsolescence that integrally captures and communicates the varying extent to which different combinations of design directions and circular business model types can be expected to be successful as a result of different product types, life cycle stages and circular business model types, with the aim of providing guidance to industrial designers (and other business professionals) in selecting design directions and circular business model types when designing for managing obsolescence. Secondly, it highlights a gap in the literature with regard to the extent to which a combination of design directions and circular business models can be expected to be successful. As such, it indicates the need for further research should there be a desire to make the concept of managing obsolescence and the design methodology for managing obsolescence operational as part of (the transition to) an absolute circular economy.

Insight into Where and in Collaboration with Whom to Apply these Methods in the Product Innovation Process

The thesis found that with managing obsolescence, the contribution of industrial designers in the product innovation process expands towards the start of the process, changing the role of industrial designers from a predominantly operational to a more business strategic one.

In the design methodology of design for managing obsolescence, industrial designers design a product for one or more use cycle(s) of predetermined duration and/or intensity, potentially by multiple users, *over the product's entire product lifetime, ahead of time.* The notion that underlies design for managing obsolescence is that – since product lifetime when defined in terms of obsolescence is not solely determined by the properties of the tangible product – industrial designers can, in close cooperation with other business functions, like marketing, make use of (coordinated changes in) the intangible component of a value proposition to

systematically compensate for changes in the properties of the tangible product that result from interventions for preserving product integrity along its obsolescence profile.

In the case of a smartphone, the call rates of a refurbished smartphone could for example be lowered as compared to those of a new smartphone to increase its attractiveness and thus create a viable value proposition around it. In the case of baby strollers, customers could for example participate in a swapping system that would allow them to match the type of stroller with their current needs (e.g., a bigger stroller with a baby cot or a small lightweight unit once their child is older) at an attractive price point, if they would be willing to use strollers whose frames for example have been used before (ResCom, 2017). By designing the tangible component in conjunction with the intangible component of the value proposition, industrial designers can create long-life products that will have sufficient perceived use value at the start of every use cycle, even if the (aesthetic) properties of the tangible product have diminished as a result of interventions for preserving product integrity.

Design for managing obsolescence thus involves the iterative and co-development of the tangible product, the obsolescence profile, the longitudinal value proposition and the longitudinal

7

business model. As such, design for managing obsolescence requires industrial designers to work in close collaboration with business professionals from other business functions that are already more strategically involved, such as marketing.

Perhaps one of the most important insights gained in this thesis, however, is that managing obsolescence should not be considered a *one-size-fits-all* approach, but that (design for) managing obsolescence instead requires the careful crafting of *tailor-made* solutions that, in order to be successful, must take into account factors like product type, product (sub-) category lifecycle stage, circular business model types and cultural preferences and managerial (e.g. strategic) considerations over the entire product lifetime.

The design methodology for managing obsolescence as presented in this thesis offers (conceptual propositions for) methods to industrial designers that are intended to help them work with the above factors and to get a better grip on the requirements for the design of the tangible product when developing such *tailor-made* solutions. As the design methodology was developed *based upon theory* and has not been tested or validated empirically it is in need of future validation before it could be made operational. However, we consider these tasks to lie outside the scope of the present thesis.

7.3 FINDINGS LEADING TO THE MAIN CONCLUSIONS

The main conclusions were derived from the answers to the sub-research questions, which are described below.

7.3.1 Sub-Research Question A: "How Can Product Lifetime Extension in a Circular Economy Be Defined within the Context of Industrial Design?"

Sub-research question A was addressed in chapter 2. This chapter defined product lifetime in terms of obsolescence, thereby making it clear that product lifetime is not merely an engineering quality that can be designed into products but is also affected by intangible factors like user behaviour and wider socio-cultural influences (Cooper, 2010). Given these many factors potentially affecting product lifetime, chapter 2 argued that industrial designers cannot design products with a long or extended lifetime but can only design *a potential for* a long or extended lifetime into products. The degree to which this potential is actually realized is determined to a large extent by factors *other* than the design of the physical products or systems, such as the socio-economic context of the product (e.g., the business model that the product is embedded in).

In addition, chapter 2 presented new definitions of interventions for product lifetime extension and introduced the concepts of *presource*, *recovery horizon*, and *leakage* to accommodate the absence of the concept of waste in a circular economy. Adopting the order indicated by the Inertia Principle allowed the chapter to develop a new typology for interventions for preserving product integrity. Based on this typology for interventions for preserving product integrity, chapter 2 concluded its proposed answer to sub-research question A with the presentation of a typology for eight design approaches for preserving product integrity. This typology is shown in figure 7.3.1 and formed the starting point for chapter 3.

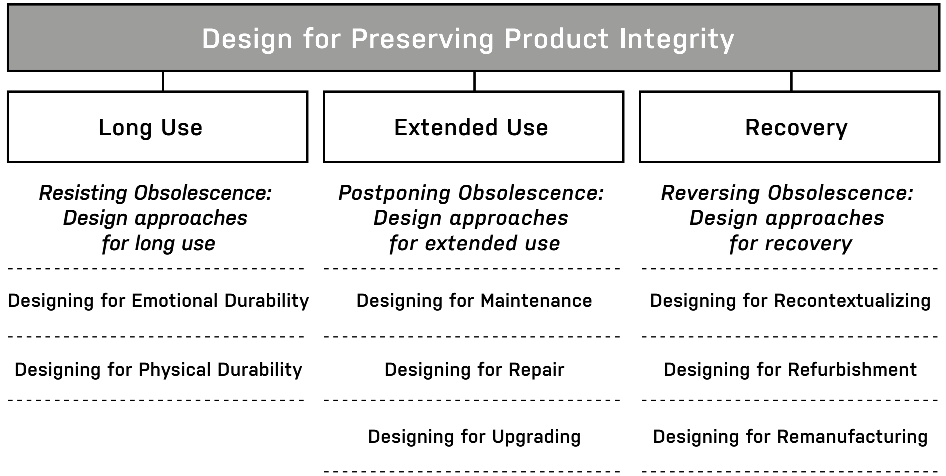


Figure 7.3.1: Design for Preserving Product Integrity: a typology for design approaches for preserving product integrity.

7.3.2 Sub-Research Question B: "What Guiding Principles and Design Interventions Can Industrial Designers Use when Designing for Long and Extended Product Lifetimes in a Circular Economy?"

Sub-research question B was addressed in chapter 3. This chapter introduced the distinction between design directions (e.g., resisting obsolescence, postponing obsolescence and reversing obsolescence), design approaches (e.g., designing for physical durability, designing for emotional durability, designing for maintenance, etc.), design principles (e.g., material selection, dis- and reassembly, modularization, identification) and design strategies (e.g., design for physical durability, design for emotional durability, design for maintenance, etc.). The distinction between design approaches and design strategies is necessary as the chapter found that virtually all of the design approaches for preserving product integrity from the typology developed in chapter 2 were supported by the same set of underlying design principles. This led to two important insights. The first insight was that the design principles selected by industrial designers in support of a particular design approach would also affect other design approaches. To make industrial designers aware of the notion that the design principles selected in support of a particular design approach more often than not also affect other design approaches, chapter 3 introduced the concept of a three-dimensional design space for preserving product integrity, as shown in figure 7.3.2.

By plotting existing products in this design space based on an assessment of the relative importance of the three design directions for preserving product integrity in the overall design intention of a product, industrial designers can use the design space for preserving product integrity as a tool to compare product designs and increase their understanding of what it means to design for different design directions and intentions for preserving product integrity.

The second insight was that the application of the design approaches (and underlying design principles) is heavily dependent on business context, i.e., the particular business objec-

Figure 7.3.2: Example products plotted in the three-dimensional design space for preserving product integrity. The three dimensions are formed by the three design directions for preserving product integrity: resisting obsolescence, postponing obsolescence and reversing obsolescence.

tive(s) the design approaches are intended to help achieve. Chapter 3 found that the business context (e.g., business and product strategy) of a product to a large extent determines how a particular design approach should be materialized. For instance, the requirements for, and the desired end result of, design for repair are different for a company that wants to retain control and have repairs exclusively performed by qualified service personnel than for a company that wants to promote repair by the users of their products. Design principles such as accessibility need to be interpreted differently by industrial designers in each of these examples depending on the particular business context (e.g., restricting access in the former and facilitating access in the latter instance). Building on this insight, chapter 3 concluded that the eight design approaches only provide practical guidance to industrial designers, i.e., only become actionable design strategies, when they are considered in conjunction with the business context of the product. For this reason, the thesis proposed to make the business context an integral part of the definition of the eight design strategies presented in chapter 3.

7.3.3 Sub-Research Question C: "What Business Model Types Can Companies Use to Create, Deliver and Capture Value from Long and Extended Product Lifetimes in a Circular Economy?"

Sub-research question C was addressed in chapter 4, which presented new definitions for the concepts of circular business model and business model circularity. The chapter introduced the concept of a circular business model for preserving product integrity and established three criteria that business models have to meet in order to qualify as such. Chapter 4 developed a new typology for circular business models for preserving product integrity, consisting of three product-service based business model types: The Classic Long Life Model, the Access Model and the Performance Model. In addition, the chapter identified three additional business model types that create and capture value from preserving product integrity but do not qualify as circular business model types for preserving product integrity. Strictly speaking, the Hybrid Classic Long Life Model, and the Hybrid Access Model do not qualify as circular business model types for preserving product integrity as their main revenue streams rely on short-lived consumables rather than long-lived durables. However, depending on how the resource loops for the consumables are set up in specific instances, they could qualify as circular business models and as such play an important role in (the transition towards) a circular economy. Business models of the third type, i.e., Gap Exploiters, not only fail to qualify as a circular business model type for preserving product integrity but can also never qualify as a circular business model at the instance level as they (by definition) have no control over

the design of the products whose lives they extend. The Gap Exploiter Model is included in the chapter as it can play an important role in the transition to an absolute circular economy.

7.3.4 Sub-Research Question D: "What Guiding Principles and Management Strategies Can Businesses Use when Creating, Delivering and Capturing Value from Long and Extended Product Lifetimes in a Circular Economy?"

Sub-research question D was addressed in chapter 5. The aim of the question was to determine what business objectives and practices industrial designers would need to facilitate when designing products for circular business models for preserving product integrity. Based on the current literature, chapter 5 identified maximizing business model circularity as the unique additional business goal that sets circular business model types for preserving product integrity apart from business model types for long and extended lifetimes in a linear economy. The chapter identified two key barriers to maximizing business model circularity: 1) Random fluctuations in the flow of obsolete products, and 2) a mismatch between the actions required for achieving environmental and economic business objectives. Next, the chapter focused on how circular business models for preserving product integrity could surmount the first key barrier, i.e., how circular business models for preserving product integrity could maximize their level of control over the flow of obsolete products. As the current literature contains only approaches for *affecting* the flow of obsolete products but none for *controlling* the flow of obsolete products, chapter 5 introduced the concept of managing obsolescence as a new management and design approach for supporting the creation, delivery and capture of value from long and extended product lifetimes in a circular economy. During the development of the concept of managing obsolescence, a gap was identified in the current literature: it does not provide insight into the factors within companies that play a role in successfully manufacturing and marketing long-life products – other than the design of the tangible product – that could potentially be leveraged by industrial designers (and other business professionals) to control the flow of obsolete products. To gain insight into the workings (and challenges) of companies currently marketing and manufacturing long-life products and (partly) fill this gap, seven company interviews were conducted. The interviews made clear that, apart from the design of the tangible product, other factors such as the type of right to the product traded, brand identity, company culture, contractual agreements, (relationships with) suppliers, (relationships with) employees, (relationships) with customers, level and type of service, channels, rules and regulations, internal organizational structure, i.e., elements from virtually the entire structure of the business model, affect the feasibility and success of manufacturing and marketing products with a long or extended lifetime and should therefore be taken into consideration when planning for managing obsolescence.

Building and expanding on the answer to sub-research question D presented in chapter 5, chapter 6 subsequently developed a methodology for design for managing obsolescence. The new design methodology for managing obsolescence consists of five new design methods and is intended to enable industrial designers to tailor their product designs to circular business models for preserving product integrity that strive to maximize business model circularity. It is different from – and adds to – existing design methodology for (sustainable) product design for products with a long and/or extended lifetime in that it takes into account the design of the tangible product as well as the design of the overall value proposition(s) and the business model(s) supporting said value proposition(s) over the entire lifetime of the product time. In addition to (and making use of) the design method of the three-dimensional design space for preserving product integrity introduced already in chapter 3, chapter 6 introduced four new design methods in support of design for managing obsolescence: (the development of) an obsolescence profile, (the development of) a longitudinal value proposition, the development of a longitudinal business model and the heuristic framework for design for managing obsolescence.

7.3.5 Sub-Research Question E: "To What Extent Can Some Combinations of Design Interventions and Business Model Types be Expected to Be More Successful in Creating, Delivering and Capturing Value from Long and Extended Product Lifetimes in a Circular Economy than Others?"

Sub-research question E pertains to surmounting the second barrier to maximizing business model circularity as identified in chapter 5, i.e., establishing how to maximize alignment between the actions required for achieving environmental and economic business objectives.

Chapter 6 found indications in the literature that, when (designing for) managing obsolescence in a circular economy, some combinations of circular business model types for preserving product integrity and design strategies for preserving product integrity mentioned above can be expected to be more successful than others. However, although the current literature on (sustainable) product design and PSS-based business model types identifies product type, PSS-based business model type and life cycle stage pertaining to a particular product as the (interdependent) factors that affect to what extent combinations of design directions (for preserving product integrity) and PSS-based business model types will be successful (see figure 7.2.2), it is inconclusive with regard to which *specific* design directions can successfully be used in conjunction with *particular* product types, *particular* types of PSS-based business models and *particular*, product related, life cycle stages.

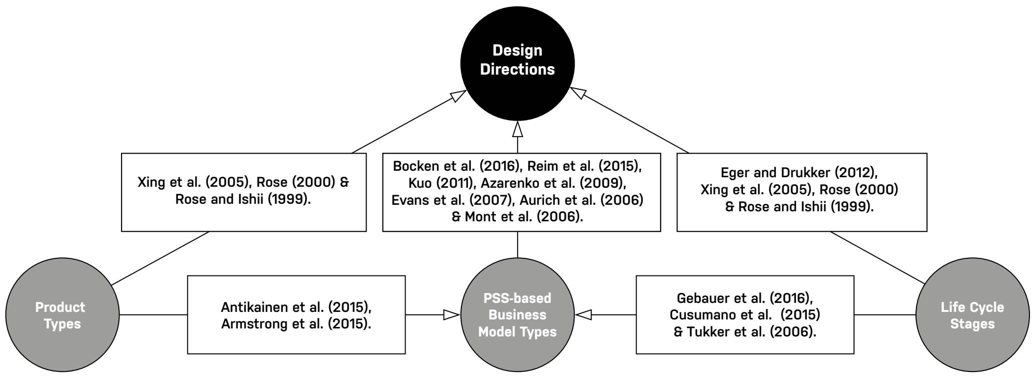


Figure 7.2.2: A visual representation of the interdependencies between PSS-based business model types, life cycle stages and product types affecting the success of applied design directions as documented in the current literature. The rounded rectangles contain references to research into the relationships between entities that is discussed in the current sub-section.

However, through subsequent expansion of the body of literature reviewed to include literature on the two remaining factors mentioned, i.e., literature on product types (e.g., WIPO, 2017; Mason, 2005; Murphy & Enis, 1986; Hirschman & Holbrook, 1982; Darbi & Karni, 1973; Nelson, 1970; Copeland, 1923) and literature on life cycle theory (e.g., Taylor & Taylor, 2012; Moon, 2005; Golder & Tellis, 2004; Rogers, 2003; Capon, 1985; Abernathy & Utterback, 1978) the thesis was able to formulate an answer to sub-research question E and develop a design method to provide guidance to industrial designers as to when to best apply which design strategies for preserving product integrity. The literature on product life cycle theory (e.g., Taylor & Taylor, 2012; Moon, 2005; Golder & Tellis, 2004; Rogers, 2003; Capon, 1985; Abernathy & Utterback, 1978) was found to be most useful here as it contains a rich discussion of (changes in) products and business-economic context over time on a general level (i.e., not pertaining to specific instances of a product). (The current literature on product types presented several classification schemes and multiple types of products but does not provide information that helped to assess the extent to which design direction and circular business model types could be expected to be successful.)

The usefulness of product life cycle theory for guiding industrial designers when designing for managing obsolescence lies in the notion that is at the core of life cycle theory, i.e., the idea that all products and the technologies that they embody go through a number of distinct stages from the moment they are conceived and introduced into the market until they are removed from the market (e.g., Taylor & Taylor, 2012; Golder & Tellis, 2004; Rink & Swan, 1979; Buzzell, 1966).

As these various stages exhibit specific characteristics and often occur in a particular order, careful reflection on the findings from the business sciences literature on product life cycle theory, in conjunction with the 20 years of industry experience of the author, allowed us to make inferences as to which particular combinations of design directions and circular business model types could be expected to be more (or less) successful in a particular product (sub-)category life cycle stage and provide an answer to sub-research question E in the form of (a conceptual proposition for) an heuristic framework for design for managing obsolescence as discussed – including its benefits and limitations – earlier in sub-section 7.2.2 and shown in figure 7.2.1.

7.4 SCIENTIFIC CONTRIBUTIONS TO THE FIELD OF SUSTAINABLE DESIGN

The results of the research presented in this thesis are of interest to the field of sustainable design for a number of reasons. The thesis has developed a new design methodology of managing obsolescence. The new design methodology was developed *"based upon theory with the purpose of helping designers to see the structure of that activity (so that they can learn or teach it, extend their capabilities, communicate it or reflect on their own or other's* [*sic*] *actions"* (Daalhuizen, 2014, p. 34). Theory-based developments, like the one presented in the thesis, of course come with the limitation that the results have not been empirically validated. However, empirical validation can be a next step (see section 7.5 Limitations and Recommendations for Further Research). More importantly, however, by taking an absolute perspective on sustainability to the circular economy concept in the development of the new design methodology, the thesis contributes to the field of sustainable design in a new and unique way, creating insights that are not evident when a circular economy is considered from a relative perspective on sustainability. For although the absolute perspective on sustainability has more or less been put on the agenda by McDonough and Braungart (2002) with their Cradle-to-Cradle® concept, and has since been used to develop design methods, for example by De Pauw (2015), it has never before been so closely connected with business objectives.

The design methodology for managing obsolescence introduces to the field of sustainable design five new methods, i.e., 1) the three-dimensional design space for preserving product integrity, 2) (the development of) an obsolescence profile, 3) (the development of) a longitudinal value proposition, 4) (the development of) a longitudinal business model, and 5) a heuristic framework for design for managing obsolescence to provide guidance in applying the first four methods. Taken together, the five new methods are intended to enable industrial designers to address the prevention of obsolescence and the extension of product lifetimes – in a way that differs markedly from the design methodology for extending product lifetimes offered by eco-design – by systematically incorporating the wider business-economic context of tangible products in their design process. Establishing the alignment of actions required to achieve environmental objectives with those required to achieve economic objectives as an essential condition for achieving business model circularity has served to clarify the role and expand the relevance of sustainable design for industry in a circular economy. The definition of design strategies for preserving product integrity and circular business model types for preserving product integrity and the framework for managing obsolescence that shows how the industry lifecycle of the products affects the likelihood of their successful combination, for the first time provides guidance to industrial designers aiming to design long-life products specifically for a circular economy.

In addition to bringing new methods, typologies and definitions to the field of sustainable design, the absolute perspective on sustainability of the methodology of managing obsolescence also provides a systemic frame of reference for ordering many of the existing eco-design methods and tools, helping their structured application. Due to its widened perspective, the design methodology of managing obsolescence can help industrial designers avoid what Ehrenfeld (2008) and Braungart et al. (2007) saw as one of the limitations and dangers inherent to a relative approach to sustainability that was already mentioned in the introduction, namely that interventions aimed at increasing eco-efficiency might unintentionally *"have adverse effects if the underlying problems are not addressed"* (De Pauw, 2015). In this way, managing obsolescence could help to increase the eco-effectiveness of eco-design tools that have so far been considered and applied only in the eco-efficiency context of a relative approach to sustainability, as for example illustrated by the use of LCAs in the circular (business-)economic and thus more systemic (instead of exclusively product focused) context of an obsolescence profile, longitudinal value proposition and longitudinal business model.

7.5 LIMITATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

7.5.1 Limitations

The Inherent Subjective Nature of Obsolescence

It is, by definition, impossible to objectively state whether a product is obsolete or not—subjectivity is at the heart of the definition of obsolescence and therefore at the heart of the definition of product lifetime. Obsolescence is largely in the eye of the beholder. It is, for example, often the user who determines whether or not a product is due for repair. A fully functional smartphone with a crack in the screen may be considered obsolete (and thus in need of immediate repair) by someone who highly values aesthetics, whereas it may seem in perfectly good working order to someone less concerned about the product's appearance. Even when the overall intention of *design for preserving product integrity* is clear, the subjective nature of obsolescence can make it difficult for designers to predict and determine the best design approach.

The Difficulty of Predicting Technological Change and Consumer Preferences over Time

Next to the inherent subjective nature of obsolescence mentioned above, the intricacies of predicting and influencing consumer preferences (as evidenced by much of the literature from the domain of marketing e.g. Frambach & Nijssen, 2017) and the difficulties in predicting the course of technological innovation (e.g. Sood et al., 2012) over time, greatly increase the complexity of developing viable obsolescence profiles, longitudinal value propositions and longitudinal business models.

The literature contains several theoretical models for predicting the course of technological innovation (Sood et al., 2012, Taylor & Taylor, 2012), some of which are deemed more accurate and sophisticated than others (Sood et al., 2012, Taylor & Taylor, 2012). The Product Life Cycle theory-based industry life cycle stage approach as followed in the thesis could be considered one of the, what Sood et al. (2012) refer to as, *"naïve generalizations of what seems to be a complex phenomenon"* (p. 977). However, the thesis has used this approach to put forward the concept of the framework for managing obsolescence, as the Product Life Cycle theory and the industry life cycle stages, however crude and limited, at present form the only documented and shared connection between design directions, business model types and technological change that illustrates their mutual interaction over time at type level in the literature. Although the thesis acknowledges that this could limit the predictive value of the framework for managing obsolescence as currently presented, it does not undermine the conceptual principle underlying the framework for managing obsolescence. It does, however, highlight the need for further research (see subsection 7.5.2) if managing obsolescence is to develop into a viable management and design approach for creating, delivering and capturing value from long and extended product lifetimes.

In this context, it is important to note that the widespread implementation of managing obsolescence and the principles of an absolute circular economy could perhaps affect the *"path*[s] *of technological innovation"* (Sood et al., 2012, p. 964), as they could change the perceived need within companies for, and thus the frequency of, introducing new products and technology.

Theoretical Approach

As an absolute circular economy is not (yet) a reality, the nature of the thesis is explorative and, notwithstanding the empirical insights resulting from the company interviews, it is largely a work of theory. This contributes to its strength but is also its main limitation.

It contributes to its strength in that the theoretical approach allowed for a level of rigour in making distinctions, defining terms and assigning categories that can only exist in theory without the compromises that inevitably come with applying the theory in practice. The theoretical approach provided the foundations for the new typology of interventions for preserving product integrity and led to the three main modes or design directions for preserving product integrity, which in turn yielded the concept of the three-dimensional design space for design for preserving product integrity. The clarity of the theoretical categorization of design directions and circular business model types for preserving product integrity that provide input for the methods of the design methodology of managing obsolescence would have been more difficult, or even impossible, to achieve if the research would have started from data acquired from the – much more muddled and complex, and currently linear – real world. Due to its theoretical origins, this thesis was able to develop and present a new design methodology that provides a structured, coherent and accessible conceptual framework to stimulate industrial designers and business professionals to start thinking about the opportunities for creating and capturing value from (extended) product lifetimes in an absolute circular economy in a new way, i.e., preserving product integrity by managing obsolescence.

The theoretical approach is also a limitation, however, as it presents a barrier to operationalizing managing obsolescence, both as a management strategy and a design methodology. What is needed now to overcome this barrier is empirical research to validate, refine or falsify the elements of the design methodology of managing obsolescence, not in the least the guiding framework for managing obsolescence, as presented in the thesis. Empirical results can enable industrial designers (and other business professionals) to learn about (the value of) managing obsolescence in practice and help them predict with increasing confidence which combinations of design directions, design strategies and business model archetypes are likely to be successful from an environmental and economic perspective and which are not.

7.5.2 Recommendations for Further Research

For (design) researchers, the design methodology of managing obsolescence offers a structure to interpret, re-evaluate and/or leverage the results of past and current research on product lifetimes and product lifetime extension (e.g., Bakker & Mugge, 2017; Cooper et al., 2015) as well as an outline of opportunities for future research, for example increasing the predictive capacities of the heuristic framework for design managing obsolescence by refining it and/or creating different versions for specific product categories or industries or deepening insights into the application of individual design principles specifically from a product lifetime perspective.

As product lifetime extension or preserving product integrity has only limited relevance in a linear economy as compared to in a circular economy, there are many aspects of product lifetime extension that have been researched in the past, but never evaluated in the context of managing obsolescence, such as research on reliability, maintenance and dis- and reassembly.

The same can be said for insights acquired from decades of design and marketing research. In a linear economy, many of these insights have mainly been used to motivate consumers to swiftly acquire new or quickly replace their old products. When re-evaluated in the context of managing obsolescence, these insights could perhaps provide new information on how consumers could be motivated to hold on to their products longer, potentially complementing extant work on this topic by for example Van Nes and Cramer (2005) and Mugge (2007).

There is much that we do not know yet with regard to preserving product integrity and managing obsolescence in a circular economy. New insights into the relationships between product lifetimes and the economic and environmental effects of interventions for preserving product integrity, based on both new empirical data and new interpretations of existing data, are needed to validate and supplement the proposed design methodology of managing obsolescence and improve the predictive power of the framework for managing obsolescence to increase their usefulness for industrial designers, other business professionals and perhaps policy makers. Looking through the lens provided by the concept of managing obsolescence could help researchers to structure findings, and compare results across different disciplines (e.g., industrial design, industrial ecology, product innovation management and business) and perhaps discover new patterns that hitherto have remained unseen. In the context of managing obsolescence, i.e., using perceived use value over time in order to preserve product integrity, the discovery of these new patterns will have consequences not only for the way new products are designed and manufactured, but also for the way new products are offered in the marketplace (for example, but not limited to, the types of rights traded, the complementary services provided, and the role and design of commercial spaces).

As a start, future research would need to test and develop the design methodology of managing obsolescence further through empirical research with industrial designers and original equipment manufacturers. Although few, if any, companies at present operate in a completely circular way and the circular economy is not yet a reality, there are many companies that have started moving towards becoming circular or that have declared their intention to do so. These companies could prove to be fertile ground for setting up future research projects.

7.6 IMPLICATIONS FOR INDUSTRIAL DESIGNERS AND OTHER BUSINESS PROFESSIONALS

In a circular economy, with waste no longer an option, recovery of (p)resources is bound to become more important. The quality of the decisions as to how to manage and recover resources over time will affect the likelihood of success of business strategies as well as government policies. The terminology, typologies and concept and design methodology of managing obsolescence presented in this thesis provide a basis for comparison and communication that can help industrial designers make design decisions, help researchers compare results, help other business professionals determine strategy, and perhaps help governments frame issues in order to create legislation that supports the transition from a linear to a circular economy.

Implications for Industrial Designers and the Role of Industrial Design

A business built around long-life products and recovery resources cannot operate without products that support that strategy, preferably by intention and design. For industrial designers, the change from linear business model types to circular business model types for preserving product integrity will result in product design briefs that contrast to those for throwaway products for a linear economy. Designing in the context of managing obsolescence means that industrial designers have to design a product for a predetermined number of use cycles of predetermined duration and/or intensity, potentially by multiple users, i.e., they have to take into consideration *the product's entire product lifetime, ahead of time.* As (the design methodology of) managing obsolescence implies that tangible products are iteratively co-designed in conjunction with obsolescence profiles, longitudinal value propositions and longitudinal business models, the role of industrial designers will change from a predominantly operational to a more business strategic one. This will require industrial designers to work together in close collaboration with professionals from other, presently already more strategically inclined, business functions such as marketing and familiarize themselves with some aspects of the theory and terminology from the business sciences. This may seem a daunting prospect at first but will ultimately increase the importance of the industrial product designer's role and skills.

The goal of managing obsolescence and design for preserving product integrity is to minimize and ideally eliminate environmental costs by preserving or restoring the product's

7

added economic value over time. Preserving product integrity or extending product lifetimes, however, does not always result in a net reduction of environmental load. Over time, newer versions of products may be developed that incorporate more efficient technologies. From that moment on, the environmental impact that arises from the prolonged use of a product may become greater than the embedded impacts of a more efficient replacement product (Bakker, Wang et al., 2014). As the Inertia Principle does not account for this, industrial designers need to understand the environmental consequences of their design interventions.

When managing obsolescence in a circular economy, the strength of the value proposition depends on how well the design of the tangible product and the business model are aligned. In the domain of marketing, (the design of) services gained strategic importance with the introduction of relationship marketing, as from that moment on services were perceived as a central part of the value proposition instead of part of the unwanted, but necessary, cost of doing business. As a result, the business function of marketing has gained strategic importance. In a similar vein, with the introduction of managing obsolescence in a circular economy, the potential for preserving product integrity that is designed (and manufactured) into a product can be expected to shift from being perceived as part of the unwanted, but necessary cost of doing business to being recognized as a central element of the value proposition(s) built around a product. Should this happen, industrial design will gain strategic importance as well. The added complexity of designing in the temporal dimension holds the promise of a re-evaluation of the industrial design profession, which in recent decades has started to suffer from the effects of commoditization as discussing business strategy is often no longer seen by business professionals as part of the industrial designer's native domain.

Implications for Other Business Professionals

For business professionals involved with manufacturing and marketing tangible, and durable, products, managing obsolescence means that they need to rethink their current business models, as these – most probably – are based on repeated product sales and not designed to profit from preserving product integrity.

For those business professionals, managing obsolescence means they have to develop, communicate and support multiple value propositions (and business models) around a single tangible product, potentially aimed at multiple users from different customer segments, i.e., like industrial designers, they too have to take into consideration *the product's entire product lifetime, ahead of time.* Switching from a single business model type to another or multiple other business model types is not easy. A transition of that magnitude is likely to introduce considerable business risks, making it a difficult decision for business managers. Although these risks cannot be avoided completely, they could be mitigated by setting up pilot projects early on, by sharing results whenever possible, and by having access to reliable empirical data with regard to managing obsolescence.

Alternative business models that will allow businesses to profit from preserving product integrity require an involvement with, and control over, a product way beyond the traditional point- of-sale horizon. In some instances, circular business models for preserving product integrity, and the extended level of control over the lifetime of products they require, could also result in the need for businesses to monitor, track and trace the whereabouts, state and usage of their products. Managing obsolescence can thus have profound implications with regard to user privacy and (perceived) user autonomy. Business professionals should be aware of these implications and prepare to renegotiate and reinvent their traditional relationship with their customers.

When ownership of products is retained for, and economic value (re)captured over, the entire lifetime of a product, as is characteristic of both the Access and the Performance model, the capital needs of a business will most likely increase as investments in products are no longer freed up at the moment of transaction. It may prove initially difficult to arrange for additional financial means to meet this need, as the value that resides in products that have been used before and/or are discarded is not yet commonly recognized. Retaining ownership of (p) resources will on the other hand also reduce the need to procure, stock and process virgin resources.

7.7 CLOSING REMARKS

A circular economy is more than a linear economy with a twist. Preserving economic value and recovering resources through managing obsolescence will interfere with what for the past sixty years have become conventional patterns of our throwaway society. And although the decision to commit to an absolute circular economy and to managing obsolescence should not be taken lightly, the different circular business model types in conjunction with the three design directions for preserving product integrity provide many options for step-wise change and as such allow for a more gradual transition, providing people with time to adjust to a new socio-economic paradigm.

However, as the thinking behind circular business model types for preserving product integrity such as the Access and Performance models gains ground and makes its way up the value chain, from user to retailer to manufacturer to raw material suppliers and big mining companies, our current notion of the concept of ownership will be challenged at a fundamental level. Managing obsolescence, when taken to an extreme, could for instance have ethical and moral consequences with regard to user autonomy and privacy.

As with all human creations, managing obsolescence can be used either for good or for ill. Planned obsolescence, a term perhaps coined with the best intentions by London (1932) shortly after the Great Depression in the United States of America in 1932, but successfully popularized with devastating environmental consequences by industrial designer Brooks Stevens in the 1950s (Adamson, 2003), is a sad example.

Aware of its potential risks, but in the hope that we as a global society will be wise enough to avoid them, this thesis offers managing obsolescence as a potential antidote to planned obsolescence and the throwaway society. In doing so, it also presents the profession of industrial design with a means to reinvent itself and redeem itself from its wasteful legacy, for: *"designers fear they are the lackeys of capitalism. Of course they are. But they are also architects of society. They hold in their hands (a little bit of) the means to define the practices of which human experience and social order are constituted"* (POPD collective, 2016).

Ayres, R. U. (1994). Industrial metabolism: Theory and policy. In B. R. Allenby and D. Richards (Eds.), *The greening of industrial ecosystems* (pp. 23–37). Washington, DC: National Academies Press.
Bakker, C.A., & Mugge, R. (Eds.) (2017). *PLATE – Product Lifetimes and The Environment, conference proceedings,* 8-10 November, 2017, Delft, the Netherlands. The Netherlands: IOS Press BV.
Bakker, C.A., Wang, F., Huisman, J., & Den Hollander, M.C. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production 69*, 10-16.
Bocken, N. M. P., De Pauw, I., Bakker, C., & Van der Grinten, B. (2016). Product design and business model strategies for a circular economy, *Journal of Industrial and Production Engineering, 33*(5), 308-320.
Braungart, M., McDonough, W., & Bollinger, A. (2007). Cradle-to-cradle design: creating healthy emissions–a strategy for eco-effective product and system design. *Journal of Cleaner Production*, *15*(13), 1337-1348.
Ciacci, L., Reck, B. K., Nassar, N. T., & Graedel, T. E. (2015). Lost by Design. *Environmental Science & Technology 49*(16), 9443– 9451.
Cooper, T. (2010). The Significance of Product Longevity. In T. Cooper (Ed.), *Longer Lasting Products - Alternatives to the Throwaway Society* (pp. 3-36). Farnham, Surrey, UK: Gower Publishing Limited.
Cooper, T., Braithwaite, N., Moreno, M., & Salvia, G. (Eds.) (2015). *PLATE – Product Lifetimes and The Environment, conference proceedings,* 17-19 June, 2015, Nottingham, UK. Nottingham, UK: Nottingham Trent University: CADBE.
Daalhuizen, J. J. (2014). *Method Usage in Design – How methods function as mental tools for designers* (Doctoral dissertation, Delft University of Technology, Delft, the Netherlands).
De los Rios, I. C., & Charnley, F. J. (2016). Skills and capabilities for a sustainable and circular economy: The changing role of design. *Journal of Cleaner Production, 160*, 109-122.
De Pauw, I. C. (2015). *Nature-Inspired Design: Strategies for Sustainable Product Development* (Doctoral dissertation, Delft University of Technology, Delft, the Netherlands).
EC (2015a). *The Durability of Products – Standard Assessment for the Circular Economy under the Eco-Innovation Action Plan.* Luxembourg, Luxembourg: Publications Office of the European Union. Retrieved July 9th, 2016 from http://bookshop.europa.eu/en/the-durability-of-products-pbKH0115726/.
Ehrenfeld, J. (2008). *Sustainability by design. A Subversive Strategy for Transforming Our Consumer Culture*. Yale University: New Haven, CT, USA.
EMF (Ellen MacArthur Foundation) (2012). *Towards the Circular Economy Vol. 1 - An Economic and Business Rationale for an Accelerated Transition.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2013). *Towards the Circular Economy Vol. 2 - Opportunities for the Consumer Goods Sector.* Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2014). *Towards the Circular Economy Vol. 3 - Accelerating the scale-up across global supply chains*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EMF (2015). *Growth Within: a circular economy*. Retrieved April 5th, 2017 from www.ellenmacarthurfoundation.org/publications.
EPEA (Environmental Protection Encouragement Agency), 2004. *Plug-In to eCycling - Guidelines for Materials Management*. Retrieved July 10th, 2016 from www.epeat.net/documents reference-docs/epa-plug-in-to-ecycling-guidelines.2004-05.pdf.
Faber, N., Jorna, R., & Van Engelen, J. O. (2005). The Sustainability of "Sustainability"—A Study into the Conceptual Foundations of the Notion of "Sustainability". *Journal of Environmental Assessment Policy and Management, 7*(01), 1-33.
Frambach, R. T., & Nijssen, E. J. (2017). *Marketing strategie.* Groningen/Houten, The Netherlands: Noordhoff Uitgevers.
Graedel, T. E., & Allenby, B. R. (2003). *Industrial Ecology* (2nd ed.). Upper Saddle River, New Jersey, USA: Pearson Education, Inc.
Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, *143*(C), 37-46.
Le Creuset (2017). Le Creuset company website: https://www.lecreuset.fr/
Lifset, R. & Graedel, T. E. (2002). Industrial ecology: goals and definitions. In Ayres, R.U. (Ed.), *A handbook of industrial ecology* (pp. 3-15). Cheltenham, UK: Edward Elgar publishing.
London, B. (1932). Ending the Depression Through Planned Obsolescence. Retrieved March 30th, 2017 from https://upload.wikimedia.org/wikipedia/commons/2/27/London_(1932) _Ending_the_depression_through_planned_obsolescence.pdf2/27London (1932) _Ending_the_depression_through_planned_obsolescence.pdf.
McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things.* New York, NY, USA: North Point Press.
Mugge, R. (2007). *Product Attachment* (Doctoral thesis, Delft University of Technology, Delft, the Netherlands).
Philips (2015). *Philips Provides Light as a Service to Schiphol Airport*. Retrieved November 20th, 2017 from https://www.philips.com/a-w/about/news/archive/standard/news/press/2015/20150416-Philips-provides-Light-as-a-Service-to-Schiphol-Airport.html.
Philips (2017). Philips company website: https://www.philips.nl.
POPD (2016). *POPD Manifesto*. Retrieved July 4th, 2016 from www.lancaster.ac.uk/ fass/projects/dnc/wkshpjul06/popd%20manifesto.pdf.
ResCom, (2017). *Bugaboo.* Retrieved November 20th from http://www.rescoms.eu/case-studies/bugaboo.
SER (Sociaal Economische Raad) (2016). Werken aan een circulaire economie: geen tijd te verliezen (Tr.: Working towards a circular economy: no time to lose). Retrieved September 3rd, 2017 from www.ser.nl/~/media/db_adviezen/2010_2019/2016/circulaire-economie.ashx.
Sood, A., James, G. M., Tellis, G. J., & Zhu, J. (2012). Predicting the path of technological innovation: SAW vs. Moore, Bass, Gompertz, and Kryder. *Marketing Science*, *31*(6), 964-979.
Stahel, W. R. (1994). The utilization-focused service economy: Resource efficiency and product-life extension. In B. R. Allenby and D. Richards (Eds.), *The greening of industrial ecosystems* (pp. 23–37). Washington, DC: National Academies Press.
Stahel, W. R. (2010). *The Performance Economy (2nd ed.)*, Hampshire, UK: Palgrave Macmillan Hampshire.
Taylor, M., & Taylor, A. (2012). The technology life cycle: Conceptualization and managerial implications. *International journal of production economics, 140*(1), 541-553.
Van Nes, N., & Cramer, J. (2005). Influencing Product Lifetime through Product Design. *Business Strategy and the Environment 14*, 286-299.
WRAP (Waste and Resources Action Programme) (2017). Circular economy definition. Retrieved March 29th, 2017 from www.wrap.org.uk/about-us/about/wrap-and-circular-economy.

Industrial product design does not set its own design goals nor is completely free in deciding how it is going to achieve them. Industrial design is guided by the strategy and objectives of a company.

APPENDIX A: THE PRODUCT INNOVATION PROCESS

In most companies built around tangible products, the process of designing the actual tangible product is but one part of a larger, ongoing, product innovation process (Van Boeijen et al., 2013; Buijs, 2012; Roozenburg & Eekels, 1995). This larger product innovation process loops back onto itself in a continuously repeating sequence of steps, i.e., *"product use, strategy formulation, design brief formulation, product development and market introduction"* (Van Boeijen et al., 2013, p. 23), whereby product use is often taken as the beginning of the continuously repeating sequence to stress that new products are always conceived, designed, developed and introduced in the context of - and often in response to the shortcomings or success of - existing products. Because larger organisations typically have more than one product in their product portfolio at any given time, their larger product innovation process often involves (strategic) planning for, and managing the development of, multiple products (e.g., products with a different function or products intended for different markets and customer segments) in parallel: *"a product mix"* (Van Boeijen et al., 2013, p.21). When the product innovation process is considered from the perspective of industrial design and in the context of the development of a single new product, the literature often uses strategy formulation or *"strategic planning"* (Roozenburg & Eekels, 1995, p. 126) instead of product use as the starting point of the continuously repeating sequence of steps in the product innovation process (e.g., Roozenburg & Eekels, 1995; Van Boeijen et al., 2013) to emphasize that the business function of industrial product design does not set its own design goals nor is completely free in deciding how it is going to achieve them. Industrial design is guided by the strategy and objectives of a company (e.g., Van Boeijen et al., 2013; Adamson, 2003; Roozenburg & Eekels, 1995; Heiskanen, 1996) The sequence of steps in this narrower perspective than becomes strategy formulation, design brief formulation, *"strict product development"* (Van Boeijen, 2013, p. 22) and market introduction. Strict product development is a term representing the interdependent processes of *"product designing"* (Van Boeijen, 2013, p. 22), *"marketing planning"* (Van Boeijen, 2013, p. 22), and *"product* [and production*] development"* (Van Boeijen, 2013, p. 22). A visual representation using this sequence of events is shown in figure A.2.1. Within this larger whole, the industrial design process (i.e., product designing) for a single tangible product is characterised by Van Boeijen et al., (2013) as a process of trial and error that - much like the larger product innovation process - *"consists of a sequence of empirical cycles"* (Van Boeijen et al., p. 19), whereby *"the knowledge of both the problem and the solution increase with each cycle"* (Van Boeijen et al., p. 19), The five successive steps within each design cycle are analysis, synthesis, simulation, evaluation and decision (Van Boeijen et al., 2013; Roozenburg & Eekels, 1995) (represented by the five small white circles surrounding the term product designing in figure A.2.1). In the analysis step, industrial designers analyse the various aspects that are related to a design goal or problem that was posed to them (Van Boeijen et al., 2013; Roozenburg & Eekels, 1995). The synthesis step is where industrial designers select and apply design strategies to generate possible solutions (Van Boeijen et al., 2013; Roozenburg & Eekels, 1995) to the particular design goal or problem that was posed to them (Van Boeijen et al., 2013; Roozenburg & Eekels, 1995) In the simulation, evaluation and decision steps that follow, potential solutions are expressed at a level suitable for testing them against the design goal or problem and either (partially) accepted or rejected. Until a product design is finally accepted in its entirety, each (partial) rejection prompts the start of a new design cycle.

The role of industrial (product) design is to generate and propose design solutions in the form of designs for tangible products that support the strategy and resulting business objectives of a company, i.e., tangible products that can be used to create perceived use value and customer surplus (Bowman & Ambrosini, 2000) in a coordinated manner that matches with how other functions within the larger company like production and marketing propose to support the strategy and business objectives of a company.

Figure A.2.1 (next page): "The entire process of one innovation loop from company strategy to market introduction" (Van Boeijen et al., 2013, p. 21) *after* Roozenburg & Eekels (1995). *The five small circles around the word 'product designing' just below the centre of the diagram represent the five successive steps of analysis, synthesis, simulation, evaluation and decision* (Van Boeijen et al., 2013; Roozenburg & Eekels, 1995) *within each successive design cycle.*

REFERENCES APPENDIX A: THE PRODUCT INNOVATION PROCESS

Adamson, G. (2003). Industrial Strength Design, How Brooks Stevens Shaped Your World. Cambridge, MA, U.S.A.: the MIT press.

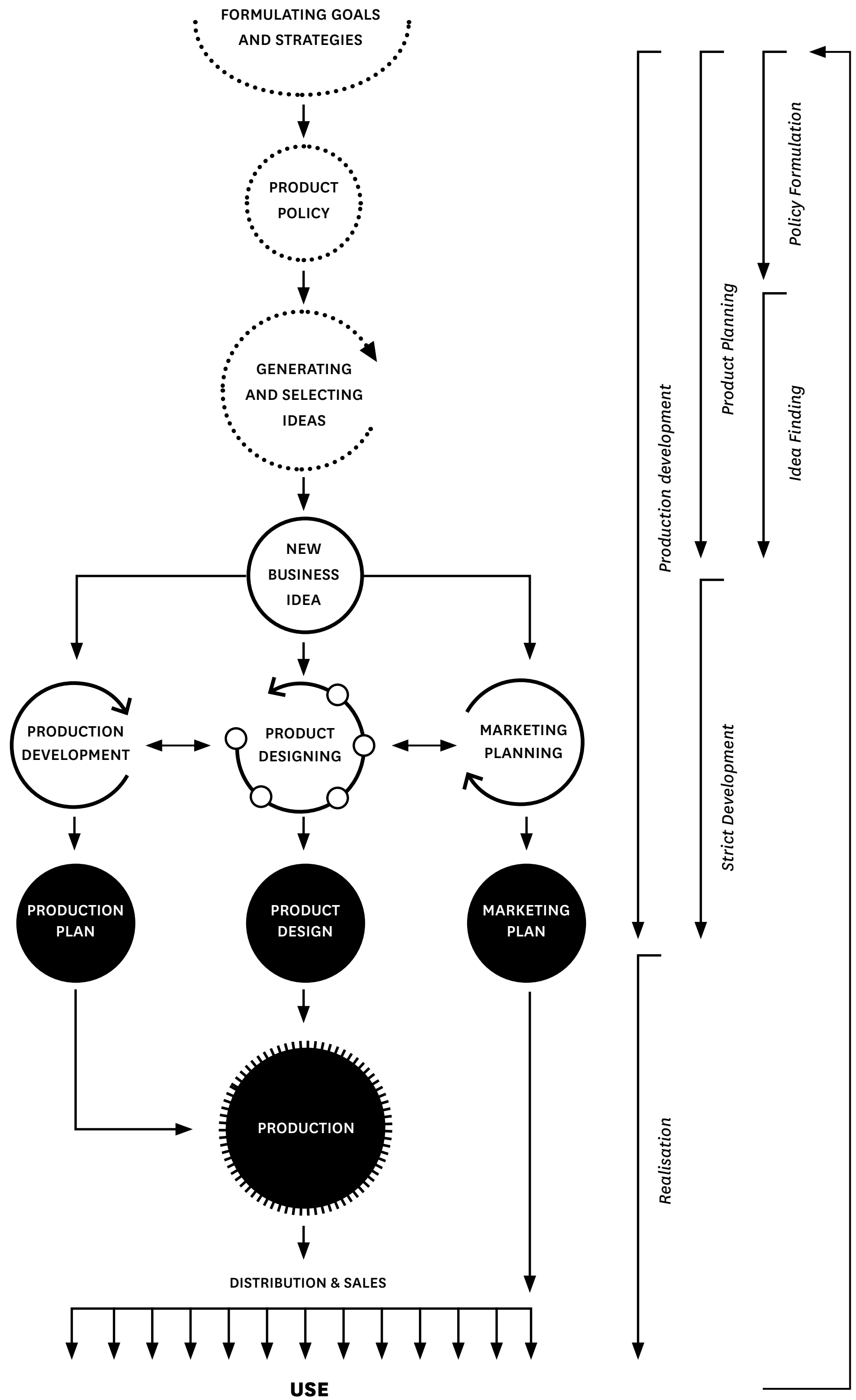
Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. *British journal of management*, *11*(1), 1-15.

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

Heiskanen, E. (1996). *Conditions for Product Life Extension.* National Consumer Research Centre Working Papers 23.

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

Roozenburg, N. F. M., & Eekels, J. (1995). *Product Design: Fundamentals and Methods*. Chichester, U.K.: John Wiley & Sons.



A

The way in which a company creates perceived use value and customer surplus in the form of goods and services and captures monetary exchange value in return by trading these goods and services with its customers, is defined by its business model.

APPENDIX B: THE BUSINESS MODEL AND RELATED CONCEPTS

B.1 Value and Profit

The root of all business is trade, defined as *"to exchange (something) for something else, typically as a commercial transaction"* (Oxford Dictionaries, 2017). It is generally believed that people are willing to trade something for something else only if they believe that, in the end, they will be better off after the trade then before: *"by and large, people spend their money on what they expect will give them most satisfaction"* (Bach, Flanagan, Howell, Levy & lima, 1987, p.92). According to Zeithaml (1991, 1988) and Bowman and Ambrosini (2000), customers assign value, e.g. *"perceived use value"* (Bowman & Ambrosini, 2000, p. 4), to a product, based on their *"beliefs about the goods, their needs, unique experiences, wants, wishes and expectations"* (Bowman & Ambrosini, 2000, p. 2), e.g. their *"perceptions of what is given and what is received"* (Bowman & Ambrosini, 2000, p. 2). The perceived use value of a product is highly subjective, as it represents a judgment of the usefulness of a product in relation to the needs of a particular customer. Both individual end-customers and organizational or industry buyers assign perceived use value to products they might want to acquire to satisfy their needs (Bowman & Ambrosini, 2000). Linder & Williander (2015), referring to Hsieh, Nickerson & Zenger (2007), stated that *"value is created by a solution to a problem of a customer at a cost less than the value of the solved problem. Value is appropriated, or captured, by charging the customer a price for the solution to the problem"* (p. 2). Perceived use value can be expressed in terms of monetary terms (e.g. *"total monetary value"* (Bowman & Ambrosini, 2000, p. 3). A customer however, will in most situations pay less than that amount, the rare exception being that of a monopoly supplier situation (Bowman & Ambrosini, 2000) The amount of money that is actually paid by the customer in exchange for the perceived use value is called the *"exchange value"* (Bowman & Ambrosini, 2000, p. 4). The difference between the total monetary value and the exchange value of a product is the *"consumer surplus"* (Bowman & Ambrosini, 2000, p. 3), often referred to by consumers as *"value for money"* (Bowman & Ambrosini, 2000, p. 3), Customers will choose the product that delivers them the highest customer surplus (Bowman & Ambrosini, 2000, p. 3). To affect the potential customers' assessments in favour of their own products, a business must differentiate its product(s) from those of its competitor(s) in a way that is valued by potential customers and ensure that its product(s) offer more consumer surplus as compared to products from its competitor(s) (Bowman & Ambrosini, 2000). A business can increase the perceived customer surplus of a product in three different ways. It can choose to increase the product's perceived use value without changing its price, it can keep the total monetary value constant but lower the price, or it can also decide to do both simultaneously (Bowman & Ambrosini, 2000).

New use value is created in businesses by the work of the people in the organization:

> inanimate resources purchased as inputs to the production process, whether they be machines, buildings, steel, computers, or flour, are incapable of transforming themselves into anything other than what they are. They need to be activated, worked on before they can contribute to the production of new use values. The tangible inputs into the production process, i.e. the use values acquired by an organization, are inert. The intervention of people is necessary to create new use values from the acquired resources (Bowman & Ambrosini, 2000, p. 5).

The above applies to tangible as well as less tangible inputs, for example information and brands (Bowman & Ambrosini, 2000). Not all new use value that is created will be perceived by potential customers as such. In addition, the mere fact that a certain amount of (physical) resources have successfully completed the manufacturing process is no guaranty that perceived use value has actually been added (Anderson et al., 2015). All that is known at that point, is that use value was altered and that the change in use value could potentially result in added exchange value (Bowman & Ambrosini, 2000). Whether new use value is perceived as such is a result of communication with the potential customer as much as of the properties of the tangible product (Simester, 2016). It is only at the time of transaction, e.g. when the product is traded with the customer for money, that a business first knows whether, and how much of, the new use value it has created can actually be converted into exchange value.

In principle, profit is generated in a transaction when the amount of exchange value realized in the transaction exceeds the total cost of the resources (including wage cost) that have been put in the process of producing the perceived use value. In practice, profit often occurs when the cumulative amount of exchange value realized in a number of transactions over a certain period of time exceeds the total cost of the resources (including wage cost) that have been put in the process of producing the perceived use value over that same period. Perceived use value, and therefore profit, can only be created through work (Fine & Saad-Filho, 2016). Although use value is always transformed by labour, it should be noted that not all labour performed within an organization results in a form of use value that is actually perceived as such by the customer and could lead to profit (Bowman & Ambrosini, 2000). To be able to capture exchange value from perceived use value and realize a profit, it is essential that a business either owns the resources used in the creation of perceived use value or is able to appropriate a part of the rents paid for those resources (Bowman & Ambrosini, 2000).

If a company is to survive long term however, a focus on short-term financial profit and exchange value is not sufficient. A business must also plan and take action to secure the capacity to capture value over the long term, i.e., maintain its competitiveness and safeguard its position in the market (Tukker et al., 2006).

B.2 The Business Model: Concept, Ontology and Classification

B.2.1 The Business Model Concept

The way in which a company creates perceived use value and customer surplus in the form of goods and services and captures monetary exchange value in return by trading these goods and services with its customers, is defined by its business model (Teece, 2010; Zott & Amit 2010; Richardson, 2008; Osterwalder et al., 2005). The business model concept was first coined by Bellman et al. (1957). Since then, and especially in the period between the late 1990s and early 2000s, the use of the term business model has dramatically increased (Ghaziani & Ventresca, 2005). At present the term is widely used, both in management practice and scientific research (Klang et al., 2014; Wirtz et al., 2016), when referring to a description of the underlying structure of a business (Wirtz, Pistoia et al., 2016; Saxena et al., 2017). Although the rise of the business model concept has not been without criticism (Klang et al., 2014), the business model concept has over time proven valuable as a device for describing, classifying and understanding business phenomena and developing ideal types (Aversa, Furnari & Heafliger, 2015; Klang et al., 2014; Baden-Fuller & Morgan, 2010). Despite its widespread use and present popularity, it has so far been difficult to arrive at a single and universally accepted definition of the term (Saxena et al., 2017; Wirtz, Göttel & Daiser, 2016; Zott, Amit & Massa, 2011) as evidenced by the multitude of interpretations and definitions of the business model concept that exist in the current literature (e.g., Rappa, 2017; Wirtz, Pistoia et al., 2016; Boons & Lüdeke-Freund, 2013; Zott & Amit, 2013, 2010; Zott et al., 2011; Osterwalder & Pigneur, 2010; Richardson, 2008; Malone et al., 2006; Chesbrough, 2006). An in-depth discussion of the differences between the various interpretations, definitions and streams of the business model concept falls outside the scope of the thesis as detailed analyses and comparisons are extensively documented elsewhere in the literature (e.g., Saxena et al., 2017; Wirtz, Pistoia et al., 2016; Boons & Lüdeke-Freund, 2013; Osterwalder, 2004, Osterwalder et al., 2005; Casadesus-Masanell & Ricart, 2010). The thesis focuses on the commonalities in order to arrive at a working definition and conceptualization of the business model construct at a level of complexity that is sufficient for use by industrial designers.

One of the most recent and comprehensive reviews of the literature on the business model concept to date was presented by Wirtz, Pistoia et al. (2016) in their article 'Business Models: Origins, Development and Future Research'. Bringing together their findings, they proposed the following elaborate definition:

> a business model is a simplified and aggregated representation of the relevant activities of a company. It describes how marketable information, products and/or services are generated by means of a company's value-added component. In addition to the architecture of value creation, strategic as well as customer and market components are taken into consideration in order to achieve the superordinate goal of generating, or rather, securing the competitive advantage. To fulfil this latter purpose, a current business model should always be critically regarded from a dynamic perspective, thus within the consciousness that there may be the need for business model evolution or business model innovation, due to internal or external changes over time (Wirtz, Pistoia et al., 2016, p. 41).

Although the above definition by Wirtz, Pistoia et al. (2016) indicates that there is a close relation between the business model and business strategy, the two are different and not to be confused (Abraham, 2013): *"a business model is the direct result of strategy but is not, itself, a strategy"* (Casadesus-Masanell & Ricart, 2010, p. 212). The difference between the two is that *"the business strategy explains how companies hope to do better than their rivals"* (Saxena et al., 2017, p. 20) and therefore *"includes competition and implementation"* (Saxena et al., 2017, p.21), *"while the business model describes how the pieces of a business all fit together"* (Saxena et al., 2017, p. 20). Something similar can be said for the business process descriptions and the business case: although the above definition by Wirtz, Pistoia et al. (2016) indicates that they are closely related to the business model, they are definitely not the same Wirtz, Pistoia et al. (2016).

As to how business model, business strategy and business processes do relate, there is general agreement between authors (e.g., Wirtz, Pistoia et al., 2016; Zott et al., 2011; Casadesus-Masanell & Ricart, 2010; Al-Debei & Avison, 2010; Osterwalder et al., 2005) that the business model should be considered as the *"intermediate layer between business strategy and business processes including information systems"* (Saxena et al., 2017, p. 21). Casadesus-Masanell & Ricart (2010) succinctly summarized the differences between business model, strategy and business processes or tactics:

> Business Model refers to the logic of the firm, the way it operates and how it creates value for its stakeholders and Strategy refers to the choice of business model through which the firm will compete in the marketplace while Tactics refers to the residual choices open to a firm by virtue of the business model it chooses to employ (p.196).

It follows from the business model definition by Wirtz, Pistoia et al. (2016) mentioned earlier that the development of a business model is not a 'one-time' event, only to be done at the start of a business, but rather is an ongoing and iterative process. Extending the findings of Casadesus & Ricart (2010), Boons & Lüdeke-Freund (2013) observed that *"strategic interaction between rivals results in competition based on business model modifications"* (p. 10). If a company is to remain successful, e.g., achieve the economic and environmental goals it has set for itself, its business model needs to be adjusted and maintained continuously over time (Saxena et al., 2017).

The influence of the business model on a business' ability to successfully create and sustain a competitive advantage is such, that business model innovation (BMI), e.g., innovation of the business model itself, in recent times *"has established itself as a cornerstone of innovation - next to product, service, and process innovation"* (Wirtz et al., 2016, p. 2). Saxena et al. (2017) observed

> there is a general consensus on what constitutes a 'successful business model': it should be dynamic, change with the environment or make the environment change (business processes and the environment are not static). A compelling value proposition is necessary to attract the customers and capture value from them. A strong business model is unique, hard to replicate/imitate and provides compelling offers to customers while being grounded in reality (p. 20).

The value proposition mentioned above by Saxena et al. (2017), though considered central, is only but one of the components that make up a business model. The value proposition and the other components that together make up a business model, will be discussed in more detail in the next subsection.

B.2.2 Business Model Ontology

Osterwalder et al. (2005) distinguished three levels on which business models can be analysed and discussed:

1. The concept level addresses the question of what a business model is and *"consists of definitions of what a business model is and what belongs in them and meta-models that conceptualize them"* (p. 10);
2. The type level addresses the question of which types of business models resemble each other and "*consists of several types or meta-model types of business models that are generic but contain common characteristics"* (p. 10);
3. The instance level addresses the question of what the business model of a specific company is and *"consist of either concrete real world business models or of conceptualization, representations, and descriptions of real world business models"* (p. 10).

A graphical representation of the three levels as presented by Osterwalder et al. (2005, p. 9) is shown in figure B.2.2 below:

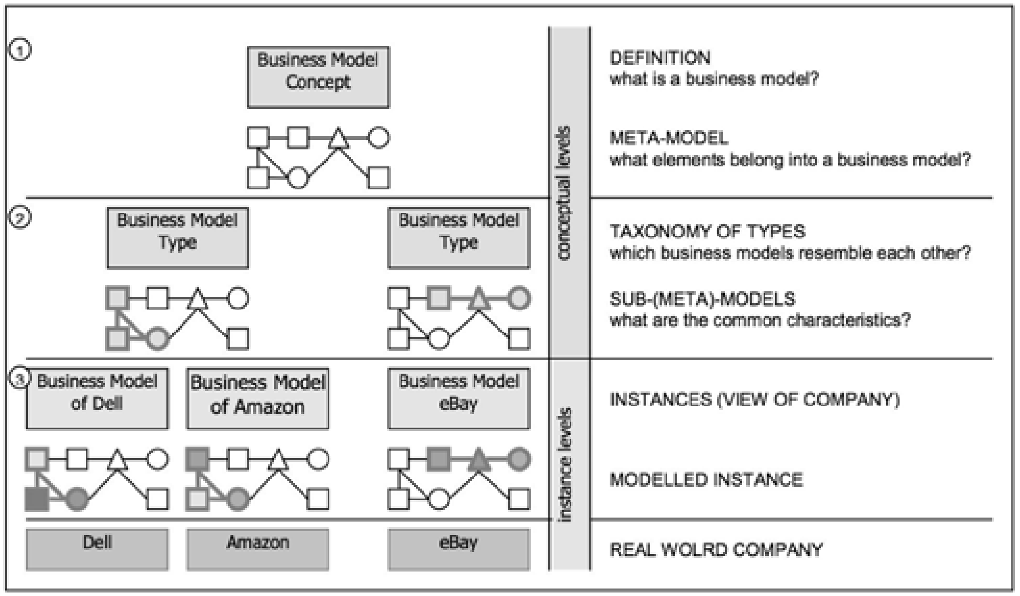


Figure B.2.2: Diagram of the three conceptual levels at which the business model concept can be analysed and discussed. Reproduced from Osterwalder et al., 2005, p. 9.

The concept level (see figure B.2.2) represents the most fundamental of the two conceptual levels and is referred to in the literature as the ontological level (Wirtz, Pistoia et al.,2016; Saxena et al., 2017). Gruber (1991) defines 'ontology' as *"a specification of a representational vocabulary for a shared domain of discourse — definitions of classes, relations, functions, and other objects"* (p. 199). At present, many different business model ontologies co-exist in the literature (e.g., Wirtz, Pistoia et al., 2016; Zott & Amit, 2010; Osterwalder & Pigneur, 2010, Doganova & Eyquem-Renault, 2009; Chesbrough & Rosenbloom, 2002). These have in common that they all examine and attempt to describe, albeit in their own ways, *"what the business model actually is"* (Saxena et al., 2017, p. 21). After their extensive examination of the extant literature on the business model concept, Wirtz, Pistoia et al. (2016) arrived at nine components that make up and thus are part of every business model. Wirtz, Pistoia et al. (2016) presented these components as interacting 'partial models', classified as 'strategic components', 'customer & market components' and 'value creation components', that together constitute the complete business model. The nine components, or partial models, and their constituent elements as proposed by Wirtz, Pistoia et al. (2016) are shown in figure B.2.3 on the next page.

Although the model by Wirtz, Pistoia et al. (2016) as shown in figure A.2.3 is deemed comprehensive, it describes the business model concept in a manner and at a level of detail that is greater and more complex than is necessary for use in the thesis. Agreeing with Gronum, Steen & Verreynne (2015) that *"the practical appeal of the business model concept lies in its ability to present, clarify and simplify the essential elements of how the business creates*

B

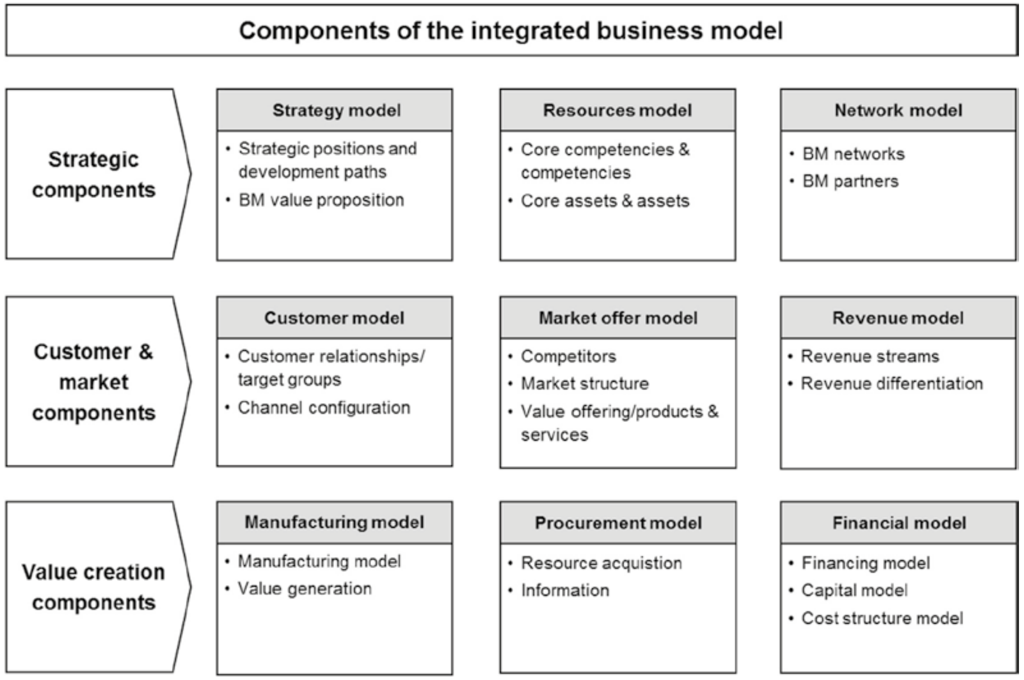


Figure B.2.3: Components and partial models of an integrated business mode. Reproduced from Wirtz, Pistoia et al., 2016, p. 44.

and captures value" (p. 588) - in this instance to and for industrial designers - the thesis will for its the argument turn to a simpler business model conceptualization as proposed by Osterwalder & Pigneur (2010). Similar to that of Wirtz, Pistoia et al. (2016), the business model conceptualization by Osterwalder & Pigneur (2010) was developed on the basis of an extensive review of the existing literature. In addition to this however, Osterwalder & Pigneur (2010) tested and refined their findings over the years with a community of 470 practitioners from 45 countries (Osterwalder & Pigneur, 2010). As a result, their business model conceptualization, including its graphical representation known as 'the Business Model Canvas' (Osterwalder & Pigneur, 2010) has at present become a well-known and widely used business model representations in industrial design education, industrial design practice and research (e.g., IDEO, 2017; Lewandowski, 2016; Bakker, Den Hollander et al., 2014; Barquet, De Oliveira, Amigo, Cunha & Rozenfeld, 2013) The Business Model Canvas with its nine 'building blocks' is shown in figure B.2.4 below.

The reduced complexity of Osterwalder & Pigneur's (2010) business model conceptualization and visualization may also reduce their usability for more complex analyses. It will however in the context of the thesis not result in over-simplification: although they do not align one-on-one with the sub-model components as proposed by Wirtz, Pistoia et al. (2016), it may be clear from comparing figures B.2.3 and B.2.4 that the nine building blocks of the model proposed by Osterwalder & Pigneur (2010) can accommodate virtually all of the components and elements from the model by Wirtz, Pistoia et al. (2016) shown in figure B.2.3, albeit in a different grouping. The business model conceptualization and visualization by Osterwalder & Pigneur (2010) furthermore have the important advantage that they are well-known and widely used by industrial design practitioners and industrial design students.

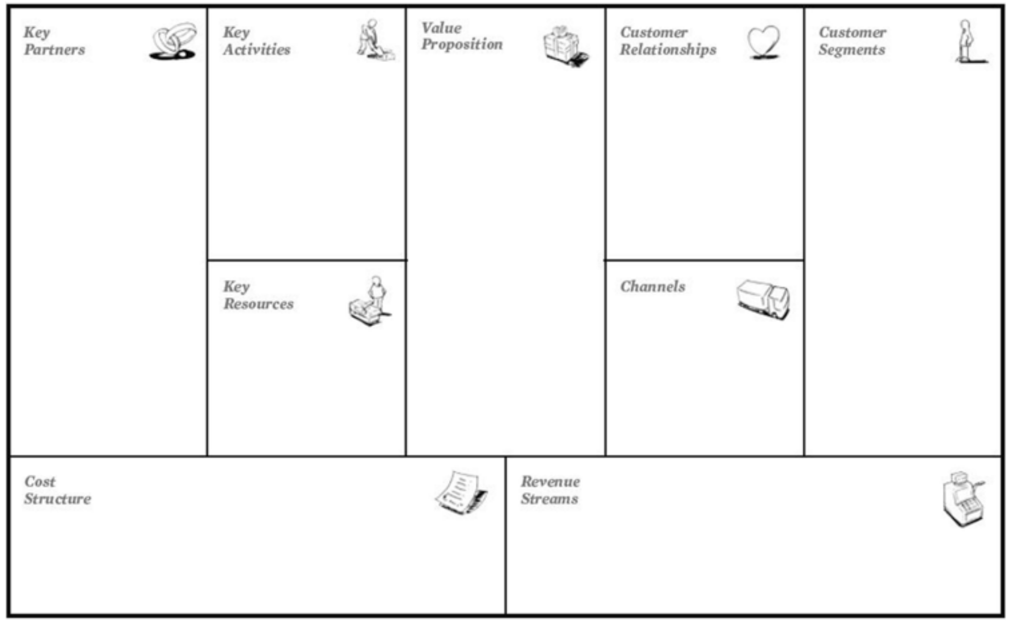


Figure B.2.4: The Business Models Canvas, a graphical representation of the set of nine business model building blocks as proposed by Osterwalder and Pigneur (2010). Reproduced from Osterwalder and Pigneur, 2010, p.44.

REFERENCES APPENDIX B: THE BUSINESS MODEL AND RELATED CONCEPTS

Abraham, S. (2013). Will business model innovation replace strategic analysis? *Strategy & Leadership, 41*(2), 31-38.
Al-Debei, M., & Avison, D. (2010). Developing a unified framework of the business model concept. *European Journal of Information Systems, 19*, 359–376.
Anderson, E., Lin, S., Simester, D., & Tucker, C. (2015). Harbingers of failure. *Journal of Marketing Research*, *52*(5), 580-592.
Aversa, P., Furnari, S., & Haefliger, S. (2015). Business model configurations and performance: A qualitative comparative analysis in Formula One racing, 2005–2013. *Industrial and Corporate Change*, *24*(3), 655-676.
Bach, G. L., Flanagan, R., Howell, J., Levy, F., & Lima, A. (1987). *Microeconomics* (11th ed.). Englewood Cliffs, NJ, USA: Prentice-Hall.
Baden-Fuller, C., & Morgan, M. S. (2010). Business Models as Models. *Long Range Planning, 43*, 156-171.
Bakker, C. A., den Hollander, M. C., Van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. Leidschendam, the Netherlands: TU Delft Library/ Marcel den Hollander IDCR.
Barquet, A. P. B., De Oliveira, M. G, Amigo, C. R, Cunha, V. P., & Rozenfeld, H. (2013). Employing the business model concept to support the adoption of product-service systems (PSS). *Industrial Marketing Management, 42*, 693-704.
Bellman, R., Clark, C., Malcolm, D. G., Craft, C. J., & Ricciardi, F. M. (1957). On the Construction of a Multi-Stage, Multi-Person Business Game. *Operations Research 5*(4), 469- 503.
Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, *45*, 9-19.
Bowman, C., & Ambrosini, V. (2000). Value creation versus value capture: towards a coherent definition of value in strategy. *British journal of management*, *11*(1), 1-15.
Casadesus-Masanell, R., & Ricart, J. E. (2010). From strategy to business models and onto tactics. *Long Range Planning, 43*, 195-215.
Chesbrough, H. (2006). *Open business models: How to thrive in the new innovation landscape.* Boston, MA, USA: Harvard Business School Press.
Chesbrough, H., & Rosenbloom, R. S. (2002). The role of the business model in capturing value from innovation: Evidence from Xerox Corporation's Technology Spin-off Companies. Industrial and Corporate Change, 11(3), 529–555.
Doganova, L. & Eyquem-Renault, M. (2009). What do business models do? Innovation devices in technology entrepreneurship. *Research Policy, 38*, 1559–1570.
Fine, B., & Saad-Filho, A. (2016). *Marx's Capital.* London, UK: Pluto Press.

B

Ghaziani, A. & Ventresca, M. J. (2005). Keywords and cultural change: frame analysis of Business model public talk, 1975–2000. *Sociological Forum, 20,* 523–559.
Gronum, S., Steen, J., & Verreynne, M. L. (2016). Business model design and innovation: Unlocking the performance benefits of innovation. *Australian Journal of Management*, *41***(3), 585-605.**
Gruber, T. R. (1993). A Translation Approach to Portable Ontology Specifications. *Knowledge Acquisition, 5*(2), 199-220.
Hsieh, C., Nickerson, J., & Zenger, T. (2007). Opportunity discovery, problem solving and a theory of the entrepreneurial firm. *Journal of Management Studies, 44*(7), 1255–1277.
IDEO (2017). Business Model Canvas. Retrieved February 14th, 2017 from https://challenges.openideo.com/challenge/web-start-up/inspiration/business-model-canvas.
Klang, D., Wallnöfer, M., & Hacklin, F. (2014). The Business Model Paradox: A systematic Review and Exploration of Antecedents. *International Journal of Management Reviews, 16*, 454-478.
Lewandowski, M. (2016). Designing the Business Models for Circular Economy - Towards the Conceptual Framework. *Sustainability, 8*(43), 1-28.
Linder, M., & Williander, M. (2015). Circular business model innovation: inherent uncertainties. *Business Strategy and the Environment, 26*(2), 182-196.
Osterwalder, A. (2004). The Business Model Ontology—A proposition in a design science approach (Doctoral thesis). Université de Lausanne, Lausanne, France.
Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation*. Hoboken, NJ, USA: John Wiley & Sons.
Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying Business Models: Origins, Present, and Future of the Concept. *Communications of Association for Information Systems, 15*, 1-43.
Oxford Dictionaries (2017). Definition of 'trade'. Retrieved March 15th, 2017 from https://en.oxforddictionaries.com/definition/trade.
Rappa, M. (2017). *Managing the Digital Enterprise - Business Models on the Web*. Retrieved March 11th, 2017 from http://digitalenterprise.org/models/models.html.
Richardson, J. (2008). The business model: an integrative framework for strategy execution. *Strategic Change, 17*(5-6), 133-144.
Saxena, K. B. C., Deodhar, S. J., & Ruohonen, M. (2017). The Business Model Concept and its Use. In *Business Models Innovation in Software Product Industry, 13-34*. India: Springer India.
Simester, D. (2016). Why Great New Products Fail. *MIT Sloan Management review*, Spring 2016 Issue. Retrieved March 15th, 2017 from http://sloanreview.mit.edu/article/why-great-new-products-fail/.
Teece, D. J. (2010). Business models, business strategy and innovation. *Long range planning*, *43*(2), 172-194.
Tukker, A., Van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In A. Tukker and U Tischner (Eds.), N*ew Business for Old Europe - Product-service development, competitiveness and sustainability* (pp. 22-34). Sheffield, UK: Greenleaf Publishing Ltd.
Wirtz, B. W., Göttel, V. & Daiser, P. (2016). Business Model Innovation: Development, Concept and Future Research Directions. *Journal of Business Models, 4*(1), 1-28.
Wirtz, B. W., Pistoia, A., Ullrich, S., & Göttel, V. (2016). Business Models: Origin, Development and Future Research Perspectives. *Long Range Planning 49*, 36-54.
Zeithaml, V. A. (1988). Consumer Perceptions of Price, Quality and Value: A Means- End Model and Synthesis of Evidence. *Journal of Marketing, 52*, 2-22.
Zeithaml, V. A. (1991). Consumer Perceptions of Price, Quality and Value: A Means-end Model and Synthesis of Evidence. In Kassarjian, H. H., & Robertson, T. S., (eds.), *Perspectives in Consumer Behavior* (pp. 27–53). Englewood Cliffs, NJ, USA: Prentice- Hall.
Zott, C., & Amit, R. (2010). Business model design: an activity system perspective. *Long range planning*, *43*(2), 216-226.
Zott, C., & Amit, R. (2013). The business model: A theoretically anchored robust construct for strategic analysis. *Strategic Organisation, 11*(4), 403-411.
Zott, C., Amit, R., & Massa, L. (2011). The business model: Recent developments and future research. *Journal of Management, 37(4),* 1019-1042.

APPENDIX C: THE STRATEGY CONCEPT: DEFINITION, EVOLUTION AND ONTOLOGY

C.1 Strategy Concept and Definition

In the business sciences literature, the term *strategy* refers to a description of *"how companies hope to do better than their rivals"* (Saxena et al., 2017, p. 20) that *"includes competition and implementation"* (Saxena et al., 2017, p.21). According to Porter (1996), *"strategy is the creation of a unique and valuable position, involving a different set of activities"* (p.1). Alternative definitions of the term strategy that provide more insight into the particular issues a strategy is concerned with were for example presented by Hofer & Schendel (1978), i.e., a strategy is *"the fundamental pattern of present and planned resource deployments and environmental interactions that indicates how the organization will achieve its objectives"* (p. 25) and Learned, Christensen, Andrews and Guth, (1965), i.e., *"Strategy is the pattern of objectives, purposes, or goals and the major policies and plans for achieving these goals, stated in such a way as to define what business the company is in or is to be in and the kind of company it is or is to be"* (p. 15). Although the concept of strategy is sometimes interpreted in the literature (e.g., Glueck, 1980; Hofer & Schendel, 1978) as a *"plan"* (Glueck, 1980, p. 9), Freedman (2013) took special care to emphasise that a strategy is *"much more than a plan"* (p. xi): Whereas *"a plan supposes a sequence of events that allows one to move with confidence from one state of affairs to another* [a] *strategy is required when others might frustrate one's plans because they have different and possibly opposing interests and concerns"* (p. xi). Being more than a plan, a well-developed strategy can help prepare a company for the future, put it in a position so it can turn emerging contingencies to its advantage, and as such can help a business to get *"more out of a situation than the starting balance of power would suggest"* (Freedman, 2013, p. xiii). There is no general agreement on a single definition and a multitude of interpretations and definitions of the strategy concept co-exist in the current literature (e.g., Saxena et al., 2017; Stickdorn, Schneider, Andrews & Lawrence, 2014; Freedman, 2013; Brown & Katz, 2011; Martin, 2007; Dunne & Martin, 2006; Matthyssens, Martens & Vandenbempt, 1998; Porter, 1996; Montgomery & Porter, 1991; Glueck, 1980; Hofer & Schendel, 1978; Learned et al., 1965). An in-depth discussion of the differences between the various interpretations, definitions and streams of the strategy concept however, is considered to fall outside the scope of the thesis as detailed analyses, comparisons and discussions of the different perspectives are extensively documented elsewhere in the literature (e.g., Stickdorn et al., 2014; Freedman, 2013; Chandler et al., 1999; Matthyssens et al., 1998; Hofer & Schendel, 1978). The thesis instead chooses to focus on the commonalities in the various interpretations. It proposes a working definition and conceptualisation of the strategy concept that, in order to set it apart from a mere plan, is a combination of a slightly modified version of the definition of strategy as provided by Porter (1996) and the assertion by Freedman (2013) that a strategy can help a business to get *"more out of a situation than the starting balance of power would suggest*" (p. xiii):

A *strategy* is the creation of a unique and valuable position, involving a distinctive set of activities that enables an organisation to get more out of a situation than the starting balance of power would suggest.

In the proposed definition, Porter's (1996) term different has been replaced by the term distinctive, as the latter term removes the implicit need for a basis for comparison

C

that result from Porter's (1996) use of the term different whilst retaining - perhaps even amplifying - Porter's (1996) original intention. The reason why the thesis has adopted Porter's (1996) definition as part of the newly synthesised definition lies in its formulation. Porter's (1996) definition is formulated in such a way that it captures and conveys the essence of the strategy concept. At the same time, the use of the relative loose terms of 'creation' and 'involving' provides the definition with sufficient ambiguity to accommodate a wide range of different interpretations of the strategy concept from the literature.

C.2 The Evolution of the Strategy Concept

The strategy concept has its origins in warfare and has been in use for thousands of years (Freedman, 2013). Although both the use of the term strategy in the domain of the business sciences (Freedman, 2013) and *"the development of the concept of strategy as an explicit tool for managing economic and social organizations"* (Hofer & Schendel, 1978, p. 13) are of far more recent origin (Freedman, 2013; Montgomery & Porter, 1991; Porter, 1980; Hofer & Schendel, 1978), the adoption of the strategy term and concept in the domain of the business sciences has been swift and complete. In line with Montgomery & Porter (1991), who asserted that already during the 1980's, *"strategy became a full-fledged management discipline"* (p. xi), Freedman (2013) found that *"references to business strategy were rare before 1960 ... they started to take off during the 1970's and by 2000 became more frequent than references to military strategy"* (p. xiii).

The first use and development of the strategy concept in a business context was prompted by the increasing complexities of managing organisational structures that continued to grow in size over time (Hofer & Schendel, 1978). This led to the early development of strategy as a means to align, structure and control (Freedman, 2013; Hofer & Schendel, 1978) the various functions within a single organisation by making goals and policies explicit (Hofer & Schendel, 1978). Over time this resulted in the basic hierarchy of strategies, i.e., corporate level strategy, business level strategy and functional level strategy (Hofer & Schendel, 1978), as it is known in the literature today. There is however a second aspect to the strategy concept. In addition to its use as a means to promote coherence within a single organisation, it can also be used as a tool to help outperform competitors in the competition between organisations (Alsem, 2017; Freedman, 2013; Porter, 1996; 1980; Hofer & Schendel, 1978). The development of this second, and by now dominant, aspect of the strategy concept gained momentum in the 1980's (Alsem, 2017) after Porter (1980) had stressed the importance of strategy as a means to outperform the competition and presented his three *"generic competitive strategies"* (p. 34), i.e., *"overall cost leadership"* (p. 35), *"differentiation"* (p. 35) and *"focus"* (p. 35). Although both aspects of the strategy concept, i.e., strategy as a means to increasing organisational efficiency as well as a means to increase organisational effectiveness, are important when operating in a competitive environment, there is general agreement in the literature of the business sciences (e.g., Drucker, 2006; Porter, 1998, 1996, 1980; Hofer & Schendel, 1978; Barnard, 1968) that *"in general ... organizations depend much more for their long-run success and survival on improvements in their effectiveness (that is how well they relate to their environments) than on improvements in their efficiency"* (Hofer & Schendel, 1978, p.2). Each of the strategy levels mentioned earlier addresses a different question (Matthyssens et al., 1998; Hofer & Schendel, 1978). Corporate level strategy addresses the question *"What set of businesses should we compete in?"* (Hofer & Schendel, 1978, p.15). It may be clear that it depends on the size and structure of an organisation whether this corporate level of strategy development is required or not (Matthyssens et al., 1998; Hofer & Schendel, 1978). Business level strategy addresses the question *"How should we compete in the XYZ business?"* (Hofer & Schendel, 1978, p.15), e.g., in which product and/or market segment or segments a company should be active. At the functional level, strategy addresses the question of how to compete with a certain product in a certain market segment (Hofer & Schendel, 1978).

In line with the military origins of the strategy concept (Freedman, 2013), the traditional approach to strategy development in companies built around tangible products was top-down: from corporate strategy (if applicable) to business level strategy to functional (area) strategy (Hofer & Schendel, 1978). At business strategy level, extensive internal and external analyses would basically help companies choose the business strategy most suited to their specific situation from a number of standard strategy types. Examples of these standard strategy types are Porter's (1980) three generic competitive strategies as mentioned earlier and the "[market] *share-increasing strategies"* (p. 163), *"growth strategies"* (p. 164), *"profit strategies"* (p. 166), *"market concentration and asset reduction strategies"* (p. 169), *"turnaround strategies"* (p. 172) and *"liquidation and divestiture strategies"* (p. 174) as presented by Hofer & Schendel (1978). After the strategy at business level had been determined, the strategies at functional level would then be developed to provide support for that particular business strategy. In these traditional approaches to strategy development, the tangible product was considered the core element of the value proposition, a view on doing business described by Sheth & Uslay (2007) as the *"exchange paradigm"* (p. 1). Services required to support and enable the transaction were to be kept at a minimum and considered as an undesirable but necessary cost of doing business (Beuker, 2014). This changed however with the advent and development of relationship marketing (Alsem, 2017; Gummeson, 1999, 1987; Webster, 1992; Grönroos, 1997, 1991; Berry, 1983), that shifted the business focus from one-time transactions to *"attracting, maintaining and ... enhancing customer relationships* [over time]" (Berry (1983) as cited in Egan, 2011, p.35). With the arrival of the relationship paradigm - to paraphrase Sheth & Uslay (2007) - it became increasingly clear that the provision of services was not merely a cumbersome and efficiency related topic to be relegated to the functional strategy level, but potentially was one of the most important parts of a value proposition - its economic value sometimes exceeding that of other business activities (Kimbell, 2014) - and therefore an important aspect to take into account when determining business level strategy. Although the scientific discussion in the domain of the business sciences as to how to conceptualise services as yet remains unresolved (Kimbell, 2014; Lovelock & Gummeson, 2004; Vargo & Lusch, 2004; Zeithaml et al., 1985), the realisation that *"understanding value and the nature of relations between people and other people, between people and things, between people and organisations, and between organisations of different kinds"* (Kimbell, 2014, p.51) is what ultimately is important in *"the creation of a unique and valuable position*[s]" (Porter, 1996, p.1), helped blur the boundaries between business level and functional level strategy development as well as between the roles of industrial product design and marketing (Kimbell, 2014) (as evidenced by the ongoing discussion regarding the conceptualisation services (e.g., Lovelock & Gummeson, 2004; Vargo & Lusch, 2004; Zeithaml et al., 1985). This helped create openings for new approaches to business level strategy development such as design thinking (e.g., Brown & Katz, 2011; Martin, 2007; Dunne & Martin, 2006), *"service design thinking"* (Stickdorn et al., 2014, p.12) and *"Blue Ocean Strategy"* (Kim & Mauborgne, 2005; 2004) or *"blue sky programs"* (Matthyssen et al., 1998, p. 171). These more recent approaches to strategy development differ from the more traditional approaches to strategy development as they break free from the confines imposed by the unidirectional, hierarchic order of strategy development and the generic 'either/or' business strategy templates as for example proposed by Hofer & Schendel (1978) and Porter (1980) and allow for movement towards more bi-directional "and/and" approaches to strategy development (Beuker, 2014; Stickdorn et al., 2014). These "and/and" approaches allow aspects from different generic strategies to be mixed and recombined (Matthyssen et al., 1998; Baden-Fuller & Stopford, 1994; Stopford & Baden-Fuller; 1990) and view services (and how and where these are provided (Kimbell, 2014; Booms & Bitner, 1981) not as undesirable though necessary cost, but rather as an essential part of value propositions involving tangible products (Beuker, 2014).

REFERENCES APPENDIX C: THE STRATEGY CONCEPT: DEFINITION, EVOLUTION AND ONTOLOGY

Alsem, K.J. (2017). *Strategische marketing planning: Theorie, technieken en toepassingen.* Groningen, the Netherlands: Noordhoff Uitgevers.

Baden-Fuller, C., & Stopford, J.M. (1994). *Rejuvenating the mature business.* Boston, MA, Harvard Business School Press.

Barnard, C.I. (1968). *The Functions of the Executive.* Cambridge, MA, USA: Harvard University Press. (First published 1938).

Berry, L.L. (1983). Relationship marketing. In Berry, L.L., Shostack, G.L. & Upsay, G.D. (Eds.) *Emerging Perspectives on Service Marketing* (pp. 25-28). Chicago, IL, USA: American Marketing Association.

Beuker, R. (2014). Strategic Management: Why corporations do what they do. In Stickdorn, M., Schneider, J., Andrews, K. & Lawrence, A. (Eds.), *This is Service Design Thinking -basics - tools - cases.* Amsterdam, the Netherlands; BIS Publishers.

Booms, B., & Bitner, M.J. (1981). Marketing Strategies and Organisational Structures for Service Firms. In Donnelly, J, & George, W. (eds.), *Marketing of Services*. Chicago, USA: American Marketing Association, 47-52.

Brown, T., & Katz, B. (2011). Change by design. *Journal of Product Innovation Management 28*(3): 381–383.

Chandler, A., Hagstrom, P., & Solvell, O. (Eds.) (1999). *The Dynamic Firm: The Role of Technology, Strategy, Organization, and Regions*. Oxford University Press

Drucker, P. (2006). *The Effective Executive.* New York, NY, USA: HarperCollins Publishers (First published in 1967).

Dunne, D., & Martin, R. (2006). Design Thinking and How It Will Change Management Education: An Interview and Discussion. *Academy of Management Learning & Education 5*(4), 512-523.

Egan, J. (2011). *Relationship Marketing – exploring relational strategies in marketing* (4th ed.). Harlow, Essex, U.K.: Pearson Education Limited.

Freedman, L. (2013). *Strategy - A History.* New York, NY, USA: Oxford University Press.

Glueck, W.F. (1980). *Business policy and Strategic Management* (3rd ed.). New York, NY, USA: McGraw-Hill.

Grönroos, C. (1991). The Marketing Strategy Continuum: Towards a Marketing Concept for the 1990s, *Management Decision, 29*(1), 7-13.

Grönroos, C. (1997). Value-Driven Relational Marketing: From Products to Resources and Competencies. *Journal of Marketing Management, 13*(5), 407-419.

Gummeson, E. (1987). The New Marketing - Developing Long Time Interactive Relationships. *Long Range Planning 20*(4), 10-20.

Gummeson, E. (1999). *Total Relationship Marketing - Rethinking Marketing Management: From 4P's to 30R's*. Oxford, UK: Butterworth-Heineman.

Hofer, C.W., & Schendel, D. (1978). Strategy Formulation: Analytical Concepts. St. Paul, MN, USA: West Publishing Company.

Kim, W.C., & Mauborgne, R. (2004). Blue Ocean Strategy. *Harvard Business Review, October issue*, 76-85.

Kim, W.C., & Mauborgne, R. (2005). *Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant*. Boston, MA, USA: Harvard Business School Press.

Kimbell, L. (2014). Marketing: connecting with People, Creating Value. In Stickdorn, M., Schneider, J., Andrews, K. & Lawrence, A. (Eds.), *This is Service Design Thinking -basics - tools - cases.* Amsterdam, the Netherlands: BIS Publishers.

Learned, E.P., Christensen, C.R., Andrews, K.R., & Guth, W.D. (1965). *The business policy - Text and cases*. Homewood, IL, USA: Richard Irwin.

Lovelock, C., & Gummeson, E. (2004). Whither Services Marketing? In Search of a New Paradigm and Fresh Perspectives. *Journal of Service Research 7*(1), 22-41.

Martin, R. (2007). *The Opposable Mind: How Successful Leaders Win Through Integrative Thinking.* Boston, MA, USA: Harvard Business School Publishing.

Matthyssens, P., Martens, R., & Vandenbempt, K. (1998). *Concurrentiestrategie en marktdynamiek.* (In Dutch. Tr.: Competition Strategy and Market Dynamics). The Netherlands: Kluwers Bedrijfsinformatie.

Montgomery, C.A., & Porter, M.E., (eds.), (1991). *Strategy - Seeking and Securing Competitive Advantage.* Boston, MA, USA: Harvard Business School Publishing Division.

Porter, M.E. (1980). *Competitive strategy - Techniques for Analysing Industries and Competitors.* New York, N.Y., USA.: The Free Press.

Porter, M.E. (1996). What is Strategy? *Harvard Business Review*, November-December issue.

Porter, M.E. (1998). *Competitive Advantage - Creating and Sustaining Superior Performance.* New York, NY, USA: Free Press.

Saxena, K. B. C., Deodhar, S. J., & Ruohonen, M. (2017). The Business Model Concept and its Use. In *Business Models Innovation in Software Product Industry, 13-34*. India: Springer India.

Sheth, J.N., & Uslay, C. (2007). Implications of the Revised Definition of Marketing: From Exchange to Value Creation. *Journal of Public Policy & Marketing 26*(2): 302-307.

Stickdorn, M., Schneider, J., Andrews, K., & Lawrence, A. (Eds.) (2014). *This is Service Design Thinking -basics - tools - cases.* Amsterdam, the Netherlands: BIS Publishers.

Stopford, J. M., & BadenFuller, C. (1990). Corporate rejuvenation. *Journal of Management Studies, 27*(4), 399-415.

Vargo, S., & Lusch, R. (2004). The Four Service Marketing Myths: Remnants of a Goods-based Manufacturing Model. *Journal of Service Research 6*(4), 324-335.

Webster, F.E. (1992). The Changing Role of Marketing in the Corporation. *Journal of Marketing 56*(10), 1-17.

Zeithaml, V.A., Parasuraman, A., & Berry, L. (1985). Problems and Strategies in Services Marketing. *Journal of Marketing 49* (Spring), 33-46.

C

The discipline of marketing - in its various roles - is destined to play a key role in the newly proposed business practice of managing obsolescence as it touches on every step of the process of product innovation and value creation in businesses.

APPENDIX D: THE MARKETING CONCEPT: DEFINITION, EVOLUTION AND ROLES

D.1 Marketing: Concept and Definition

According to the literature, *"marketing is the business function that identifies current unfulfilled needs and wants, defines and measures their magnitude, determines which target markets the organization can best serve, and decides on appropriate products, services and programs to serve these markets"* (Kotler, 1984, p. xvii). The American Marketing Association (2017) defined marketing in 2013 as *"the activity, set of institutions, and processes for creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society at large"*. The earlier (i.e., 2004 and 2007) versions of this new definition of the marketing concept has been subject to much academic discussion (e.g., Gundlach & Wilkie, 2009; Gundlach, 2007; Grönroos, 2006; Zinkan & Williams, 2007) with regard to their *"Implications for Scholarship and the Role and Responsibility of Marketing in Society"* (Gundlach, 2007, p. 1). The definition was however later adjusted over time to accommodate much of the earlier critical remarks and suggestions. The thesis chooses to integrally adopt the above definition in its most recent (i.e., 2013) formulation for two reasons. The first is that it fits particularly well with the newly defined circular business models archetypes for preserving product integrity as presented in section 4.6 and the newly developed concept of managing obsolescence as proposed in section 5.6, as it expands the historic focus of marketing on a more narrow transactional, *"exchange paradigm"* (Sheth & Uslay, 2007, p. 1) of the older (i.e., 1985 (Sheth & Uslay, 2007) definition of the marketing concept to also include (Grönroos, 2006) a relational paradigm (e.g., Alsem, 2017; Gummeson, 1999, 1987; Webster, 1992; Grönroos, 1991; Berry, 1983), i.e., *"creating and delivering value through* [enduring] *customer relationships"* (Sheth & Uslay, 2007, p.1). The second reason is that the definition is more in line with the circular economy concept and how it views economic (business) activity than some other definitions, such as Kotler's (1984) narrower description claiming that the goal of marketing is to *"serve these markets"* (p. xvii), by clearly stating that marketing instead is aimed at *"creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society at large"* (American Marketing Association, 2017).

As can perhaps already be seen from the particular formulation of the above definition, marketing is a multi-layered concept. Alsem (2017) describes this layering as a *"marketing hierarchy"* (p. 22) that can be interpreted at three levels: marketing as culture (e.g., customer-orientation and brand-orientation), marketing as strategy (e.g., selecting customer segments and positioning) and marketing as tactics (e.g., deploying the various P's, like product, price, promotion, place (Alsem, 2017; Kimbell, 2014; Kotler, 1984) and, more recently *"participants (the human actors involved in the service encounter), processes (procedures, mechanisms and flows of activities) and physical evidence (the physical surroundings and tangible clues"* (Kimbell, 2014, p. 49; Booms & Bitner, 1981) in order to achieve business objectives). The layering of the marketing concept as described by Alsem (2017) can also be recognized in Kotler's (1984) definition of the process that marketing professionals use to fulfil their role. According to Kotler (1994) *"the marketing management process consists of analyzing market opportunities, researching and selecting target markets, developing marketing strategies, planning marketing tactics, and implementing and controlling the marketing effort"* (p. 61). An important element of the marketing management process is marketing research. The thesis integrally adopts the definition of marketing research as it was proposed by the American Marketing Association (2017):

Marketing research is the function that links the consumer, customer, and public to the marketer through information--information used to identify and define marketing opportunities and problems; generate, refine, and evaluate marketing actions; monitor marketing performance; and improve understanding of marketing as a process. Marketing research specifies the information required to address these issues, designs the method for collecting information, manages and implements the data collection process, analyzes the results, and communicates the findings and their implications.

D.2 The Evolution of Marketing

Some authors claimed that the origins of marketing can be traced to as far back as seventeenth century Japan (Kotler, 1984; Drucker, 1973). In the West however, marketing in a business context *"first appeared in the early twentieth century marketing in the form of marketing research departments"* (Kotler, 1984, p. 21). These marketing research departments were considered as *"adjuncts to the sales department"* (p. 21) and their *"task was to develop information that would make it easier for sales departments to sell"* (p. 21). Soon the realisation within companies dawned however, that in an increasingly complex and competitive world, it was no longer enough for a company to merely try to find customers for the products it already manufactured (Kimbell, 2014). As manufacturers began to understand that instead of trying to find customers that fit their existing products, they needed to try *"to understand what customers might want and then produce that"* (Kimbell, 2014, p. 46), marketing shifted from being product-oriented to being customer-oriented (Alsem, 2017; Kimbell, 2014). From the 1980's onward companies started to become aware that being successful required more than being customer-oriented alone (Alsem, 2017). In addition to being customer-oriented, companies also needed to strive to outperform its competitors (Alsem, 2017; Porter, 1980), consistently and over the long-term (Alsem, 2017; Day & Wensley, 1988). This could be achieved by creating *"sustainable competitive advantage"* (Porter, 1996, p.1; Alsem, 2017), by anticipating and pro-actively catering to the needs of customers (Alsem, 2017), i.e., anticipating future developments and develop products for which there could be a potential need (Alsem, 2017) and by building, improving and maintaining stakeholder (i.e., company internal and external) relationships (Alsem, 2017; Day & Wensley, 1988). From being customer-oriented, marketing became what in the current literature is known as market-oriented (Alsem, 2017; Kohli & Jaworski, 1990; Narver & Slater, 1990). Being market-oriented means not only being customer-oriented, but to in addition being focused on promoting *"interfunctional coordination"* (Alsem, 2017, p. 24) between stakeholders in and outside the company. From 1990 onwards, the nature of marketing changed again (Alsem, 2017). This time its focus has shifted and expanded from one-time transactions to *"attracting, maintaining and ... enhancing customer relationships* [over time]*"* (Berry (1983) as cited in Egan, 2011, p.35), i.e., relationship marketing (e.g., Alsem, 2017; Gummeson, 1999, 1987; Grönroos, 1997; 1991; Webster, 1992; Berry, 1983).

D.3 Roles of Marketing Within a Company

As may be evident from the marketing hierarchy and the definitions of marketing, the marketing management process and marketing management presented above, marketing fulfils multiple roles within a company (Alsem, 2017; Kotler, 1984). It provides business management with input for strategic business planning through *"analyzing market structure and behaviour"* (Kotler, 1984, p. 62), it *"research*[es] *and select*[s] *marketing opportunities"* (ibid.), it *"develop*[s] *marketing strategies"* (p. 62), it *"plan*[s] *marketing tactics"* (p. 62) and it *"implement*[s] *and control*[s] *the marketing effort"* in an ongoing cycle (Van Boeijen et al., 2013; Buijs, 2012).

The (ongoing) product innovation process as discussed in section 1.2 and Appendix A: The Product Innovation Process and the (ongoing) marketing management process are tightly interwoven and the various steps as described above can therefore easily be found in the product innovation process diagram from figure A.2.1. As such, the various roles of marketing can be seen to touch upon every step of the product innovation process in businesses, i.e., *"product use, strategy formulation, design brief formulation, product development and market introduction"* (Van Boeijen et al., 2013, p. 23). With more recent developments like *"service design thinking"* (Stickdorn et al., 2014, p.12), that built on and evolved from 'relationship marketing' (Alsem, 2017; Gummeson, 1999, 1987; Webster, 1992; Grönroos, 1991; Berry, 1983), the role of marketing is becoming more complex as some elements of the business tactics (Reim et al., 2015) it used in support of trading tangible products, i.e., services, now are becoming an integral – and sometimes the most important part (see section 4.5 and Appendix C: The Strategy Concept: Definition, Evolution and Ontology) of the product-service based value proposition itself (Kimbell, 2014; Grönroos, 1997).

The discipline of marketing - in its various roles - is destined to play a key role in the newly proposed business practice of managing obsolescence as it touches on every step of the process of product innovation and value creation in businesses, plays an essential role in formulating the design brief for industrial designers (Van Boeijen et al., 2013; Kotler, 1984) and already for decades is the business function that is geared towards seeking out and leveraging future (socio-economic and technological) developments in support of developing business strategy, functional strategies, and products that anticipate on (potential) future potential needs (Alsem, 2017).

REFERENCES APPENDIX D: THE MARKETING CONCEPT: DEFINITION, EVOLUTION AND ROLES

Alsem, K.J. (2017). *Strategische marketing planning: Theorie, technieken en toepassingen.* Groningen, the Netherlands: Noordhoff Uitgevers.
American Marketing Association (2017). About AMA. Definition of Marketing. Retrieved January 18th, 2017 from: www.ama.org/AboutAMA/Pages/Definition-of-Marketing.aspx
Berry, L.L. (1983). Relationship marketing. In Berry, L.L., Shostack, G.L. & Upsay, G.D. (Eds.) *Emerging Perspectives on Service Marketing* (pp. 25-28). Chicago, IL, USA: American Marketing Association.
Booms, B. & Bitner, M.J. (1981). Marketing Strategies and Organisational Structures for Service Firms. In Donnelly, J, & George, W. (eds.), *Marketing of Services*. Chicago, USA: American Marketing Association, 47-52.
Buijs, J. A. (2012). *The Delft Innovation Method; a design thinker's guide to innovation.* The Hague, the Netherlands: Eleven international Publishing.
Day, G.S., & Wensley, R. (1988). Assessing Advantage: A Framework for Diagnosing Competitive Superiority. *Journal of Marketing, 52*, 1-20.
Drucker, P. (1973). *Management: Tasks, Responsibilities, Practices.* New York, NY, USA: Harper & Row.
Egan, J. (2011). *Relationship Marketing – exploring relational strategies in marketing* (4th ed.). Harlow, Essex, U.K.: Pearson Education Limited.
Grönroos, C. (1991). The Marketing Strategy Continuum: Towards a Marketing Concept for the 1990s, *Management Decision, 29*(1), 7-13.
Grönroos, C. (1997). Value-Driven Relational Marketing: From Products to Resources and Competencies. *Journal of Marketing Management, 13*(5), 407-419.
Grönroos, C. (2006). On defining marketing: finding a new roadmap for marketing. *Marketing Theory 6*(4), 395-417.
Gummeson, E. (1987). The New Marketing - Developing Long Time Interactive Relationships. *Long Range Planning 20*(4), 10-20.
Gummeson, E. (1999). *Total Relationship Marketing - Rethinking Marketing Management: From 4P's to 30R's*. Oxford, UK: Butterworth-Heineman.
Gundlach, G. T. (2007). The American Marketing Association's 2004 definition of marketing: Perspectives on its implications for scholarship and the role and responsibility of marketing in society. *Journal of Public policy & marketing, 26*(2), 243-250.

D

Gundlach, G. T., & William L. Wilkie, W. L. (2009). The American Marketing Association's new definition of marketing: Perspective and commentary on the 2007 revision. Journal of Public Policy & Marketing, 28(2), 259-264.
Kimbell, L. (2014). Marketing: connecting with People, Creating Value. In Stickdorn, M., Schneider, J., Andrews, K. & Lawrence, A. (Eds.), *This is Service Design Thinking -basics - tools - cases.* Amsterdam, the Netherlands: BIS Publishers.
Kohli, A.K, & Jaworski, B.J. (1990). Market Orientation: The Construct, Research, Propositions, and Managerial Implications. *Journal of Marketing 54*(1), 1-18.
Kotler, P., 1984. *Marketing Management* (5th ed.), London, UK: Prentice/Hall International.
Narver, J.C., & Slater, S.F. (1990). The Effect of Market Orientation on Business Profitability. *Journal of Marketing, 54*(4), 20-35.
Porter, M.E. (1980). *Competitive strategy - Techniques for Analysing Industries and Competitors.* New York, N.Y., USA.: The Free Press.
Reim, W., Parida, V., & Örtqvist, D. (2015). Product–Service Systems (PSS) business models and tactics–a systematic literature review. *Journal of Cleaner Production*, *97*, 61-75.
Sheth, J.N., & Uslay, C. (2007). Implications of the Revised Definition of Marketing: From Exchange to Value Creation. *Journal of Public Policy & Marketing 26*(2): 302-307.
Stickdorn, M., Schneider, J., Andrews, K. & Lawrence, A. (Eds.) (2014). *This is Service Design Thinking -basics - tools - cases.* Amsterdam, the Netherlands: BIS Publishers.
Van Boeijen, A. G. C, Daalhuizen, J. J., Zijlstra, J. J., & Van der Schoor, R. S. A. (eds.) (2013). *Delft Design Guide.* Amsterdam, The Netherlands: BIS Publishers.
Webster, F.E. (1992). The Changing Role of Marketing in the Corporation. *Journal of Marketing 56*(10), 1-17.
Zinkhan, G.M., & Williams, B.C. (2007). The New American Marketing Association Definition of Marketing: An Alternative Assessment. *Journal of Public Policy & Marketing, 26*(2), 284-288.

APPENDIX E: THE PRODUCT LIFE CYCLE AND RELATED CONCEPTS

E.1 Introduction

According to the business literature (Capon, 1985; Hofer, 1975; Levitt, 1965), one of the most powerful concepts to assist in the process of formulating a business strategy is *"product life cycle theory"* (Windrum & Birchenhall, 1998, p. 109). In his 1975 paper, "Toward a Contingency Theory of Business Strategy", Hofer went as far as to claim that *"the most fundamental variable in determining an appropriate business strategy* [for a business] *is the stage* [of their product] *in the product life cycle"* (Hofer, 1975, p. 798), as each of the different product life cycle stages has its own particular dynamics and therefore requires its own particular product design and business strategies for businesses to be successful from a business-economic point of view (Abernathy & Utterback, 1978; Hofer, 1975; Levitt, 1965). Capon (1985) later reiterated Hofer's (1975) claim, describing the product life cycle concept as

> one of the more pervasive concepts in marketing literature. In its fully articulated form this concept has practical relevance for the marketing manager in formulating product, pricing, distribution, and promotional strategies. The concept is also valuable for product portfolio analysis and setting strategic objectives (p. 1)

Over time, the product life cycle concept has proven to possess *"an enduring appeal"* (Day, 1981, p. 60) because of its *"intuitive logic"* (Day, 1981, p. 60) and *"considerable descriptive value when used as a systematic framework for explaining market dynamics"* (Day, 1981, p. 60). Largely due to its apparent simplicity (Day, 1981), it *"has been increasingly used by business firms"* (Tellis & Crawford, 1981, p. 125). and *"in academia as a framework for product management, strategic planning, cost and financial aspects, retaining, purchasing, international trade and as a framework for linking manufacturing to marketing"* (Tellis & Crawford, 1981, p. 125), and has been the dominant life cycle type (as compared to the technology life cycle and industry life cycle concepts) in the life cycle literature (Taylor & Taylor, 2012). The *"Bass model"* (Bass, 2004, p. 1833), a mathematical model describing the product life cycle curve, has since its introduction in 1969 become *"one of the most widely applied models in management science"* (Bass, 2004, p. 1833), spawning many model variations and refinements over time (Bass, 2004).

However, in spite of (or perhaps because of) its popularity and widespread use, the product life cycle concept has also been subject to doubts and, sometimes severe, criticism (Capon, 1985, Day, 1981; Tellis and Crawford, 1981). The product life cycle theory has been doubted and criticized on a number of grounds, involving *"problems associated with the theoretical* [e.g. modelling], *practical* [e.g. applicability], *specification* [e.g. levels of aggregation], *and empirical* [e.g. validity] *aspects of the PLC* [or product life cycle]*"* (Tellis & Crawford, 1981, p. 125).

Dhalla and Yuspeh (1976) denounced the product life cycle concept, arguing that the biological analogy of *"the fixed cycle of birth-growth-maturity-death, which higher living organisms pass through"* (Tellis & Crawford, 1981, p. 125), that is at the heart of the product life cycle concept was fundamentally flawed. The main reason for the alleged discrepancy between the realms of human artefacts and biology, according to Dhalla and Yuspeh (1976), was that

E

where *"in the biological world the length of each stage in the cycle is fixed in fairly precise terms; moreover, one stage follows another in an immutable and irreversible sequence… neither of these conditions is characteristic of the marketing world"* (Dhalla & Yuspeh, 1976, p. 2). Tellis and Crawford (1981) however demonstrated that the biological analogy with regard to the developments of products over time was neither far-fetched nor intrinsically flawed, as Dhalla and Yuspeh (1976) had claimed. Tellis and Crawford (1981) furthermore proposed the concept of the *"product evolutionary cycle"* (Tellis & Crawford, 1981) as an alternative to the product life cycle concept.

Contrary to the rigid order of the product life cycle concept, Tellis and Crawford (1981) allowed for the different stages (with the exception of the first, *"divergence"* (Tellis & Crawford, 1981, p. 129) stage and the last, *"demise"* (Tellis & Crawford, 1981, p. 129)) of their product evolutionary cycle concept to occur either once or repeatedly and/or change order. Holak and Tang (1990) demonstrated that, as a result, Tellis and Crawford's (1981) product evolutionary cycle concept was better suited to accommodate and reflect the subtler (e.g. managerial) influences, (marketing) differences and (legislative) developments than the product life cycle concept. However, with the exception of the aforementioned papers by Tellis and Crawford (1981) and Holak and Tang (1990), the appearances of Tellis and Crawford's (1981) product evolutionary cycle concept in the literature have been few, if any, since its introduction in 1981. In later works (e.g., Sood & Tellis, 2005; Golder & Tellis, 2004), Tellis more often and prominently made reference to, and provided support for, the product life cycle concept then to the – in some respects perhaps more elegant, flexible and therefore superior – product evolutionary concept (Tellis & Crawford, 1981).

Although this does not provide conclusive proof that the criticism of the product life cycle concept by for example Dhalla and Yuspeh (1976) is unfounded, is does suggest that most researchers looking into product growth and development over time deem the explanatory potential, predictive value and analytical resolution provided by the product life cycle theory sufficient for most applications, in spite of its imperfections.

Another part of the debate concerning the theoretical and practical value of product life cycle theory stemmed from what Capon (1985) called *"misconception …* [of] *… the appropriate level of analysis"* (p. 2). In product life cycle theory, the life cycle of a product is represented by the product life cycle curve. Buzzell (1966 as cited in Rink & Swan, 1979) defined the *product life cycle curve* as *"the unit sales curve for some product, extending from the time it is first placed on the market until it is removed"* (p. 219). In this definition, the term "unit sales" is a plural concept, implying addition and therefore requiring a clear specification of what exactly is to be added. As mentioned earlier, in product life cycle theory, the term product can be defined at four different levels of aggregation (Capon, 1985; Polli & Cook, 1969): *"category"* (Capon, 1985, p. 1), *"sub-category"* (Capon, 1985, p. 1), *"brand"* (Capon, 1985, p. 2). and *"model"* (Capon, 1985, p. 2). These various levels of aggregation determine what is to be counted in and what is not. As different sales volumes are being measured at each level of aggregation, analysis of the product life cycle curve at different levels of aggregation results in different outcomes (Capon, 1985; Polli & Cook, 1969).

At the category and sub-category levels of aggregation, the shape of the product life cycle curve in most instances is well beyond the influence of individual businesses and managers (Enis et al., 1977). *"Consistent patterns are typically found across a wide variety of products"* (Capon, 1985, p. 2), allowing for making generalizations with regard to the shape of the product life cycle curve (Rink & Swan, 1979) and the construction of (predictive) models that can be empirically validated (Bass, 2004, 1969; Golder & Tellis, 2004).

At the *brand* and *model* levels of aggregation however, the shape of the product life cycle curve can be influenced by interventions by individual businesses and managers (Capon, 1985; Enis et al., 1977; Dhalla & Yuspeh, 1976). For example, the implementation of additional advertising campaigns, or the reduction of advertising spending (Dhala & Yuspeh, 1976) for products in decline, can easily affect and distort the sales patterns at 'brand' and 'model' level (Capon, 1985) and introduce the risk that a product life cycle curve turns into a *"self-fulfilling prophecy"* (Tellis & Crawford, 1981, p.126). The varying (Capon, 1985; Polli & Cook, 1969), and often instance-specific, shapes of the product life cycle curve that result at the 'brand' and 'model' levels of aggregation, make it much more difficult to develop generalizations and achieve empirical validation at these levels than at the 'category' and 'sub-category' level of aggregation. In addition, *"analysis at the model or brand level gives little insight into such market behavior factors as competitor entry and exit"* (Capon, 1985, p. 2). Capon (1985) therefore stated that *"it is not useful to think of the product life cycle as a model or brand phenomenon"* (Capon, 1985, p. 2). It may be clear from the above that confusion about the levels of aggregation under consideration can lead to findings that are not in agreement with what was predicted by product life cycle theory, fostering disagreement and doubts (Windrum & Birchenhal, 1998; Dhalla & Yuspeh, 1976) about the theoretical and practical value of product life cycle theory.

It is therefore essential to be concise about the level of aggregation at which a product life cycle curve is construed and/or considered (Polli & Cook, 1969), both in judging the theoretical and practical value of product life cycle theory and in using it to guide business decisions.

The predictive value of the product life cycle concept for managing obsolescence resides in its ability to anticipate and prepare for changes in the wider product-market context over time in order to protect a product from becoming obsolete *before its time*. Kotler (1984) defined the concept of a "product" as *"anything that can be offered to a market for attention, acquisition, use, or consumption that might satisfy a want or need. It includes physical objects, services, persons, places, organisations and ideas"* (p. 463). Although this definition is sufficient for most purposes, an additional definition of product by Abell (1980) is presented here as it is deemed more helpful in explaining the relevance of the product life cycle concept to the management of obsolescence. In the context of the product life cycle curve, Abell (1980, as cited in Day, 1981), defined product as *"the application of a distinct technology to the provision of a particular function for a specific customer group"* (p. 61). The primary function of product life cycle analysis with regard to managing obsolescence is to assist in determining for how long a particular 'application of a distinct technology' can be expected to remain viable as part of a longitudinal value proposition. Abell (1980, as cited by Day, 1981), further stated that "*only when there is a change along one or more of these dimensions* [e.g., distinct technology, particular function and/or specific customer group] *that involves a sharp departure from the present strategies of the participating competitors … a separate life cycle* [is] *necessary"* (Abell, 1980 as cited by Day, 1981, p. 61).

As a distinct technology, particular function and specific customer group are exactly the parameters that define a product category and product sub-category, the primary function of product life cycle analysis with regard to managing obsolescence in essence comes down to determining how long a tangible product from a certain product category or sub-category will remain viable as part of a dynamic value proposition over time.

As a means for providing guidance in managing obsolescence, this thesis therefore focuses on product life cycle theory at the product category and product sub-category levels of aggregation. At these levels of aggregation, the product life cycle curve is most reliable (Capon, 1985; Kotler, 1984), can be captured in (predictive) mathematical models (Bass, 2004, 1969; Golder & Tellis, 2004) that can be empirically validated and therefore is most relevant (Abell, 1980).

A last point of criticism on the product life cycle concept that remains and has to be addressed here concerns the observation that it can be difficult for a business to unequivocally determine the exact position of their product on the product life cycle curve at a certain point in time (Day, 1981; Dhalla and Yuspeh, 1976). If a product is believed to be at a different point in the product life cycle curve than it actually is, the effects of business interventions can be unproductive or, worse, be counterproductive. However, since the introduction of the product life cycle concept in 1950 by Dean (1950), product life cycle theory has evolved and the predictive quality (Golder & Tellis, 2004) and the comprehensiveness of the mathematical models (Bass, 2004, 1996) used to describe the product life cycle curve have improved.

In the light of these developments, Dhalla and Yuspeh's (1976) claim that the product life cycle concept *"is a dangerous tool in the hands of managers who, faced with an unsatisfactory sales picture, may commit a product to premature death or abort a promising innovation"* (Tellis & Crawford, 1981, p. 126) clearly is an exaggeration. Nonetheless, it is worth noting that even those for whom the product life cycle concept has passed muster emphasize that the concept requires judicious use (Golder & Tellis, 2004; Day, 1981; Tellis & Crawford, 1981).

The potential difficulties and uncertainties in determining the (future) position of a product on the product life cycle curve are thus acknowledged and accepted here as an integral part of the application of product life cycle theory. At the same time, we argue that the potential difficulties and uncertainties experienced when employing the product life cycle concept in the service of management of obsolescence are no different from those experienced in other aspects of 'regular' strategic planning that are not related to managing obsolescence. In these latter areas, as evidenced by the literature, they have never prevented the product life cycle concept from being put to fruitful use.

Suggestions to approach and/or mitigate the effects of those potential difficulties and uncertainties have been proposed elsewhere in literature (e.g., Golder & Tellis, 2004; Day, 1981) and are therefore considered to fall outside the scope of this thesis.

In the next sections, we will discuss the product life cycle concept in more detail.

E.2 The Product Life Cycle Concept: Origin, Definition and Levels of Aggregation

Dean (1950) first proposed the concept of the "product life cycle" in 1950. Although not totally unfamiliar to business professionals, the concept found little practical uptake in business until Levitt (1965) (re)introduced the product life cycle concept in 1965 to marketers as an *"instrument of competitive power"* (Moon, 2005, p. 1). According to Levitt (1965), the product life cycle concept was particularly useful for business aiming to launch a new product, as it could help them *"foresee the profile of the proposed product's cycle"* (Levitt, 1965, p. 5) and prepare strategies and tactics for *"expanding or stretching out the life of a product"* (Levitt, 1965, p. 6). Rink and Swan (1979), citing Buzzell (1966) defined the 'product life cycle curve' as *"the unit sales curve for some product, extending from the time it is first placed on the market until it is removed"* (p. 219). In the years following its introduction, researchers have found the product life cycle concept to hold for both non-durable consumer goods (Bass, 2004; Rink & Swan, 1979; Buzzell, 1966) and durable consumer goods (Bass, 2004; Golder & Tellis, 2004; Kotler, 1984; Polli &Cook, 1969).

In product life cycle theory, the term "product" can have *"four quite distinct meanings"* (Capon, 1985, p. 1) and can be defined at different 'levels of aggregation' (Capon, 1985; Polli & Cook, 1969). Polli and Cook (1969) originally proposed three distinct levels of aggregation, ranging from abstract to concrete. At the top level, aggregation at the *"class"* (Polli & Cook, 1969, p. 388) level *"include*[s] *all those objects that, despite differences in shapes, sizes and technical characteristics are essentially substitutes for the same needs. The need must be fairly specific"* (Polli & Cook, 1969, p. 388). For example, although *"cars, airplanes, trains and bicycles all satisfy a need for transportation...only cars...satisfy the* [specific] *need for enclosed, fast, multi-passenger, overland transportation"* (Polli & Cook, 1969, p. 388). The next level down is made up out of finer partitions. Aggregation at the *"form"* (Polli & Cook, 1969, p. 388) level *"include*[s] *objects that, though not identical, are technically quite homogeneous. All objects within a product form can be meaningfully added in physical units. A product class may be partitioned in various product forms along different criteria; for example, cigarettes may be distinguished by the presence of a filter, by their length, and by menthol in the tobacco"* (Polli & Cook, 1969, p. 388). Lastly, there is aggregation at the *"brand"* (Polli & Cook, 1969, p. 388) level. *"Brands within a product form are 'unique,' apart from package differences. A brand is completely specified technically and is, of course, further identified by the trademark of the manufacturer or distributor"* (Polli & Cook, 1969, p. 388).

Although Polli and Cook (1966) aimed to avoid confusion, they unfortunately chose the term 'brand', that is rather ambiguous in its meaning (Wood, 2000), to indicate the third level of aggregation As demonstrated by Wood (2000), the uses of the term "brand" range from indicating an abstract marketing concept to one specific and "branded" product variant (the latter being the meaning intended by Polli and Cook (1969)). This lingering ambiguity with regard to the term "brand" in Polli and Cook's (1969) levels of aggregation is resolved in a set consisting of *four* levels of aggregation as was presented by Capon (1985) and that we have therefore adopted for the thesis.

The 'product category' level of aggregation consists of *"all products of all competing producers which, despite differences in appearance and performance, essentially serve a set of functional needs in a roughly similar manner*" (Capon, 1985, p. 1). According to Capon (1985)

> a set of basic customer needs is often met by a number of product categories. Typically, different product categories offer quite distinct customer benefits in satisfying common needs. Thus, for instance, passenger automobiles, bicycles, airplanes, railroads, ships, and motorcycles all provide consumer transportation. Other examples of product categories are conveyor belts, computers, audiotapes, and cameras (p. 1)

The product sub-category (Capon, 1985) level of aggregation consists of *"a homogeneous grouping of products from all competing producers that are more similar in how they are perceived and used by customers than items in a product category"* (Capon, 1985, p. 1). For example, *"within the product category of automobiles are the subcategories of sports cars,*

E

luxury cars, compacts, and subcompacts; within the product category of computers are the subcategories of mainframe, mini-/micro-, and personal computers" (Capon, 1985, p. 1).

Capon (1985) described the *brand* level of aggregation as *"all items produced by one organization in a product subcategory. Thus, Jaguar, Cadillac, and Pinto would be brands"* (p. 2).

The fourth, model, level of aggregation was described by Capon (1985) as *"an item or model produced by one organization. Thus, a 4-door Pinto station wagon would be a 'product' in the most specific sense"* (p. 2).

In the above set of four levels of aggregation Polli and Cook's (1969) term "class" has been replaced by the term "category" with an identical meaning. This choice of term is in line with Kotler (1984) and was also adopted by Golder and Tellis (2004). The term "form" (Polli & Cook, 1969; Kotler, 1984) has been replaced by the term sub-category. We prefer the latter term as it more clearly indicates the hierarchical relationship between category and sub-category. Capon's (1985) fourth level of aggregation, *model,* now accurately represents the original intention of Polli and Cook's (1969) third *brand* level of aggregation. An additional (as compared to the original three levels of aggregation by Polli and Cook (1969)) level of aggregation, e.g. *brand*, represents a level of aggregation that does justice to the broader meaning of the term "brand" as defined by Wood (2000).

In order to provide a comprehensive perspective on the levels of aggregation, it is important to note that one *"organization"* (p. 2), from Capon's (1985) definition of *brand*, can be active in multiple *product categories* and/or in multiple *product sub-categories* simultaneously, having multiple models in the market at the same time. An example of this is Apple Inc. (Apple, 2018), who in the *product category* of personal computers make products in the *product sub-categories* of desktop computers (models: Mac Pro, iMac pro, iMac and Mac Mini), laptop computers (models: MacBook Pro, MacBook and MacBook Air), tablet computers (models: iPad Pro, iPad Air and iPad Mini), in the *product category* of mobile telephones make products in the *product sub-category* of smartphones (models: iPhone and iPhone SE) and in *the product category* of watches make products in the *product sub-category* of smart watches (models: Watch and Watch Sport) (Apple, 2018).

For the reasons mentioned earlier, this thesis focuses on the product life cycle curve at the product category and product sub-category levels of aggregation.

E.3 The Product Life Cycle Curve

E.3.1 The First Part of the Product Life Cycle Curve: The Diffusion of Innovations Paradigm

Rogers (2003) defined *"diffusion"* (p. 1) as *"the process by which an innovation is communicated through certain channels over time among the members of a social system"* (p. 35). Rogers (2003) defined the term "social system" from this definition as *"a set of interrelated units that are engaged in joint problem solving to accomplish a common goal"* (p. 23) whereby *"the members or units of a social system may be individuals, informal groups, organizations, and/or subsystems"* (p. 23). According to Rogers (2003) *"the system analyzed in a diffusion study may consist of all the peasant families in a Peruvian village, medical doctors in a hospital, or all the consumers in the United States"* (p. 23).

Rogers (2003, 1958) furthermore developed a method to standardize and categorize the different types of adopters that play a role in the diffusion process based on the criterion of *"innovativeness"* (Rogers, 2003, p. 267). By taking the S-shaped adoption curve as presented by Ryan and Gross (1943) as a starting point and plotting the number of adopters over time on a frequency basis, Rogers (2003, 1958) was able to redraw Ryan and Gross' (1943) S-shaped adoption curve as *"a normal, bell-shaped curve"* (Rogers, 2003, p. 272) that has since become the standard representation for *"the dominant method of adopter categorization"* (Rogers, 2003, p. 279) in the diffusion process. Rogers (2003, 1958) next used *"two statistics, the mean ($\bar{x}$), or average, and the standard deviation (sd) ... to divide a normal adopter distribution into five categories"* (p. 280). These adopter categories and their respective percentages (in brackets) of the adopter population are: *"innovators"* (Rogers, 2003, p. 281) (2,5%), *"early adopters"* (Rogers, 2003, p. 281) (13,5%), *"early majority"* (Rogers, 2003, p. 281) (34%), *"late majority"* (Rogers, 2003, p. 281) (34%) and *"laggards"* (16%) (Rogers, 2003, p. 281). Figure E.3.1 shows the normal bell-curve with the five adopter categories as proposed by Rogers (1958, 2003).

Rogers (2003, 1958) provided descriptions for the proposed five adopter categories depicted in figure E.3.1, differentiating between the adopter categories according to a number of dimensions. The five adopter categories and their respective properties in the various dimensions as presented by Rogers (2003) are summarized in table E.3.1 below. Some of the role titles in table E.3.1 where literally provided by Rogers (2003), others have been newly synthesized here on the bases of Rogers' (2003) descriptions.

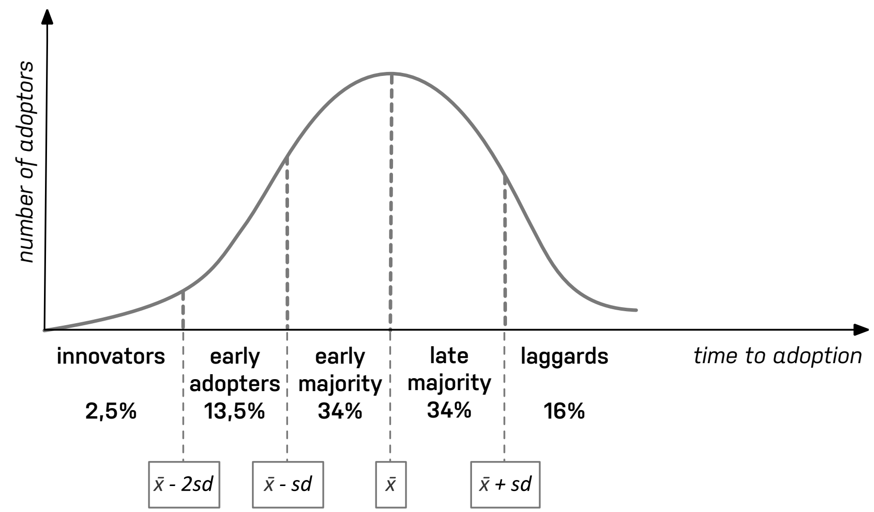


Figure E.3.1: Adopter categorization on the basis of innovativeness (adapted from Rogers, 2003)

The adopter categories as developed by Rogers (2003, 1958), discussed in table E.3.1 and shown in figure E.3.1 are *"ideal types, concepts based on observations of reality"* (Rogers, 2003, p. 282). Although *"exceptions to the ideal types can be found"* (Rogers, 2003, p. 282), they *"are designed to make comparisons* [between adopter categories] *possible"* (Rogers, 2003, p. 282). Knowledge of *"the main characteristics and values of each adopter category"* (Rogers, 2003, p. 282) of the diffusion curve for a particular social system is important to determining a business and product strategy for managing obsolescence. A better under-

E

	Innovator	Early adopter	Early majority	Late majority	Laggard
Key term associated with adopter category	*"Venturesome"* (Rogers, 2003, p. 282)	*"Respect"* (Rogers, 2003, p. 283)	*"Deliberate"* (Rogers, 2003, p. 283)	*"Skeptical"* (Rogers, 2003, p. 284)	*"Traditional"* (Rogers, 2003, p. 284)
Motivation for adopting an innovation	*"Desire for the rash, the daring, the risky"* (Rogers, 2003, p. 283)	To earn esteem from others in the social system and maintain a central position in communication networks (Rogers, 2003)	*"Deliberate willingness"* (Rogers, 2003, p. 284)	*"Economic necessity"* (Rogers, 2003, p. 284 and *"increasing peer pressure"* (Rogers, 2003, p. 284)	No other options left than to conform (Rogers, 2003)
Role description*	Gatekeeper (Rogers, 2003)	*"Missionary"* (Rogers, 2003, p. 283)	Mediator (Rogers, 2003)	Follower (Rogers, 2003)	Conformist (Rogers, 2003)
Role in social system	Seeks out and launches *"the new idea in the system by importing the innovation from outside the system's boundaries"* (Rogers, 2003, p. 283)	*"Decreases uncertainty about a new idea by adopting it, and then conveying a subjective evaluation of the innovation to near peers through interpersonal networks"* (Rogers, 2003, p. 283)	Provides *"interconnectedness in the* [social] *system's interpersonal networks"* (Rogers, 2003, p. 284),	Consolidates innovation within the social system	-
Effect(s) on diffusion process	Start diffusion process (Rogers, 2003)	Speeds up the diffusion process by helping to trigger critical mass (Rogers, 2003)	Maintains momentum for diffusion process by creating continuity between early adopters and late majority (Rogers, 2003)	Completes diffusion process (Rogers, 2003)	Signals end of diffusion process (Rogers, 2003)
Tolerance for uncertainty (e.g., willingness to innovate)	High (Rogers, 2003)	Medium (Rogers, 2003)	Low (Rogers, 2003)	Very low (Rogers, 2003)	None (Rogers, 2003)
Decision period before adopting	Very short (Rogers, 2003)	Short (Rogers, 2003)	Medium (Rogers, 2003)	Long (Rogers, 2003)	Very long (Rogers, 2003)
Degree of opinion leadership	Low (Rogers, 2003)	High (Rogers, 2003)	None (Rogers, 2003)	None (Rogers, 2003)	None (Rogers, 2003)
Financial resources	*"Substantial"* (Rogers, 2003, p. 282)	Above average**	Average**	*"Relative scarce"* (Rogers, 2003, p. 284)	*"Limited"* (Rogers, 2003, p. 284)

Table E.3.1: A summary of Rogers' (2003) *five adopter categories and their respective properties in the various dimensions. *Note: Some of the role titles where literally provided by* Rogers' (2003), *others have been newly synthesized here on the bases of* Rogers' (2003) *descriptions. **Note: Not specified by* Rogers' (2003), *Based on interpolation, under the assumption of a continuous spectrum, of the values for the financial resources dimension that were provided by* Rogers' (2003) *for the other adopter categories.*

standing of the forces that drive users or consumers within a particular social system can assist in formulating obsolescence profiles and longitudinal value propositions that appeal to the various adopter categories. The obsolescence profiles and longitudinal value propositions in turn help determine which design interventions for preserving product integrity are suited for products in the first part of a product category life cycle curve.

For durable consumer products and initial purchases (as opposed to replacement purchases) the first part of the product life cycle curve is closely related to and in essence congruent with the adoption S-curve for a particular social system as presented by Ryan and Gross (1943). This relationship between the diffusion curve and the first part of the product life cycle curve over time within a particular social system is visualized in figure E.3.2.

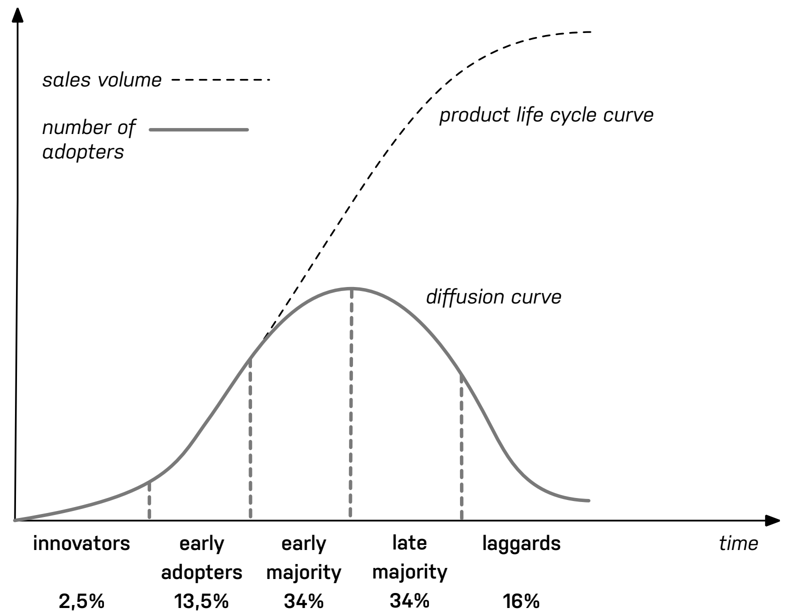


Figure E.3.2: The relationship between the diffusion curve and the first part of the product life cycle curve over time within a social system (Rogers, 2003) (after Ryan and Gross (1943) and Rogers (2003)). For visual clarity, the curves represent a hypothetical scenario where every adopter in a "social system" (Rogers, 2003, p.35) acquires one unit of a new durable consumer product.

As the number of actual adopters in a social system of a certain size increases, the number of potential adopters automatically decreases. When the number of potential adopters in a social system has gone down to zero with the (reluctant) adoption of the innovation by the last of the 'laggards', the diffusion process is completed and the innovation under consideration has reached the point of maximum *"penetration"* (Golder & Tellis, 2004, p. 207). When this happens, further sales of product will mainly consist of replacement purchases (Bass, 2004). When the social system under consideration is a potential market for a particular product, the market for that particular product at that point is said to be saturated (Peres et al., 2009).

E

E.3.2 Completing the Product Life Cycle Curve: The Bass Model and Four Product Life Cycle Stages

The second part of the product life cycle curve, the part following the completion of the diffusion process, was intentionally left out in figure E.3.2. Several options for its form have over time been proposed in the literature, leaving the exact shape of the product life cycle curve past the point of maximum adoption subject to debate (Tellis & Crawford, 1981; Rink & Swan, 1979). Much of this debate stemmed from what Capon (1985) called *"misconception …*[of]*… the appropriate level of analysis"* (Capon, 1985, p. 2). Instead of considering the product life cycle at the more predictable and reliable (Capon, 1985; Kotler, 1984) product category or sub-category levels, the product life cycle was in fact constructed and evaluated at the 'brand' and 'model' levels of aggregation where an individual business *"can manipulate at will the amount of resources committed to a model or brand"* (Capon, 1985, p. 2). The resulting wide variety of potential product life cycle shapes (Golder & Tellis, 2004; Capon, 1985; Rink & Swan, 197; 9Polli & Cook, 1969;) made generalization difficult.

At the product category and product sub-category levels that are the focus of this thesis however, the Bass Model (Bass, 1969) has played a key role in achieving the high level of consensus that currently exists in the scientific community with regard the basic shape of the product life cycle curve.

Expanding on Rogers' (2003) work, Bass (1969) developed a mathematical model for long-range forecasting of product growth that accurately (e.g. empirically validated) captured and predicted the diffusion process of innovations over time (Bass, 1969). Bass' (1969) key insight leading to the creation of the, now classic, Bass Model (Bass, 2004) was that, with the exception of the adopters from Rogers' (2003) innovator adopter category, *"adopters are influenced in the timing of adoption by the pressures of the social system, the pressure increasing for later adopters with the number of previous adopters"* (Bass, 2004, p. 1834). This realization prompted Bass to look into the mathematical theory of contagion models that were widely applied in epidemiology (Bass, 1969) as inspiration for a mathematical description of his new model for product growth. In developing his model, Bass rearranged Rogers' (2003) adopter categories into two groups: *"innovators"* (Bass, 1969, p. 216), coinciding with Rogers' (2003) innovator adopter category and *"imitators"* (Bass, 1969, p. 216), containing the other four of Rogers' (2003) adopter categories. Bass defined *innovators* as those *"adopters* [who] *are* [not] *influenced in the timing of adoption by the pressures of the social system"* (Bass, 1969, p. 216) and defined *imitators* as those *"adopters* [who] *are influenced in the timing of adoption by the pressures of the social system"* (Bass, 1969, p. 216). Based on this division, Bass (1969) created a mathematical model that *"reflected the influence of previous adopters"* (Bass, 2004, p. 1834) on ongoing and future adoption. The new model Bass created was able to predict the shape of the product life cycle curve for initial purchases (Bass, 1969) not only up to, but also beyond the point of maximum sales volume. The outcome of the mathematical model at any point in time was in essence ruled by two coefficients: the coefficient of innovation 'p' and the coefficient of imitation 'q'. Bass (1969) found that the new model behaved in such a way that if the value of the coefficient of imitation 'q', e.g. the influence of the imitators on the likelihood of adoption at a certain point in time, became larger than the value of the coefficient of innovation 'p', e.g. the influence of the innovators on the likelihood of adoption at a certain point in time, the solution would rise to a peak and then decline (Bass, 2004). This resulted in a growth model whereby *"sales grow to a peak and then level off at some magnitude lower than the peak"* (Bass, 1969, p. 215). The image in figure E.3.3 shows a reproduction of the original product growth over time, or life cycle, graph as presented by Bass in his 1969 paper "A New Product Growth for Model Consumer Durables".

"The stabilizing effect" (Bass, 1969, p. 215) that can be seen in figure E.3.3 *"is accounted for by the relative growth of the replacement purchasing component of sales and the decline of the initial purchase component"* (Bass, 1969, p. REF). Because, *"for successful new products the coefficient of imitation will ordinarily be much larger that the coefficient of innovation"* (Bass, 1969, p. 215), Bass was able to empirically validate his model and theory for a good number of new products (Bass, 1969). Over time the curve as shown in figure E.3.3 has become generally accepted as the most common shape for product life cycle curves at product category and sub-category level.

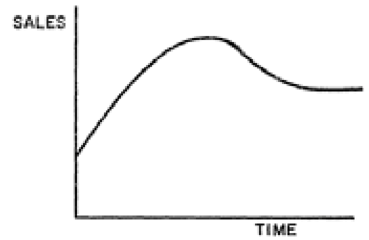


Figure E.3.3: A reproduction of the original graph for new product growth over time, or product life cycle curve, as presented by Bass in his 1969 paper "A New Product Growth for Model Consumer Durables".

In this most commonly used *"classical"* (Rink & Swan, 1979, p. 219; Tellis & Crawford, 1981) variant, the complete product life cycle curve can thus, similar to the diffusion curve from figure E.3.1 be graphically represented by *"a bell-shaped curve that is divided into several stages"* (Rink & Swan, 1979, p. 220). In the product life cycle literature, the number of proposed stages varies between four and six (Moon, 2005; Golder & Tellis, 2004; Capon, 1985; Kotler, 1984; Rink & Swan, 1979; Polli & Cook, 1969; Levitt, 1965). However, in line with Levitt (1965), Rink and Swan (1979), Kotler (1984), Golder and Tellis (2004) and Moon (2005) a division into four stages is adopted here. Golder and Tellis (2004), *"these* [four] *stages occur due to well-defined events in the history of a new product"* (p. 208). Golder and Tellis (2004) defined the four product life cycle stages as

1. Introduction is the period from a new product's commercialization until takeoff.
2. Growth is the period from a new product's takeoff until its slowdown in sales.
3. Maturity is the period from a product's slowdown until sales begin a steady decline.
4. Decline is the period of steadily decreasing sales until a product's demise (p. 208).

and the three *"well-defined events …which mark the beginning and end of the first two stages"* (p. 208) as

5. Commercialization is the point at which a new product category is first sold to consumers.
6. Takeoff is the point of transition from the introduction to the growth stage of the PLC [*product life cycle*]. It is the first dramatic and sustained increase in product category sales.
7. Slowdown is the point of transition from the growth stage to the maturity stage of the PLC. The slowdown signals the beginning of a period of level, slowly increasing, or temporarily decreasing product sales (p. 208).

E

Figure E.3.4 shows a classical product life cycle curve (Rink & Swan, 1979) with the four stages, i.e., introduction, growth, maturity and 'decline' (Golder & Tellis, 2004; Kotler, 1984; Rink & Swan, 1979), and three key events, *commercialization*, *takeoff* and *slowdown* (Golder & Tellis, 2004) marking the beginning and end of the first two stages.

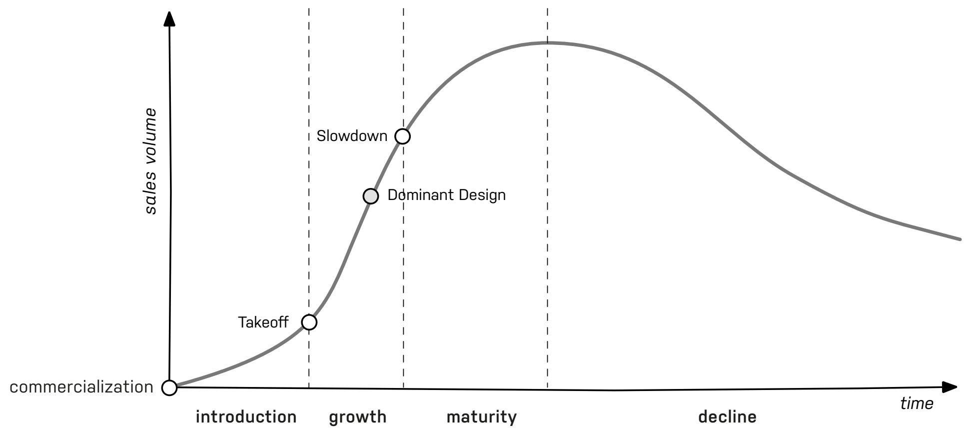


Figure E.3.4: Classical product life cycle curve (Tellis & Crawford, 1981; Rink & Swan, 1979) with the four product life cycle stages, introduction, growth, maturity and decline (Golder & Tellis, 2014; Moon, 2005; Kotler, 1984; Rink & Swan, 1979; Levitt, 1965) the three events, commercialization, takeoff and slowdown, marking the beginning and end of the first two stages (Golder & Tellis, 2014) including the approximate emergence of the dominant design (Taylor & Taylor, 2012; Kim, 2003; Anderson & Tushman, 1990; White, 1979; Abernathy & Utterback, 1978).

Each of the four stages shown in figure E.3.4 has its own dynamics and characteristics from a business-economic and technological point of view. These will be presented and discussed in more detail in section E.4. To be able to meaningfully combine the information about the diffusion dynamics (e.g., development of adopter categories) playing out on the user side of the market from this section with the information about the dynamics (e.g. development of product life cycle stages) playing out on the business side of the market that is presented in section E.4, it is important to align the two types of descriptions in time.

In figure E.3.5 the product life cycle stages and key events from the classical product life cycle curve (Tellis & Crawford, 1981; Rink & Swan, 1979) from figure E.3.4 is merged with Rogers' (2003) diffusion curve and adopter categories from figure E.3.2.

The combined diffusion and product life cycle curves in figure E.3.5 illustrate where Rogers' (2003) adopter categories are positioned in relation to the four product life cycle stages. This provides additional information as the characteristics (see table E.3.1) of the user (i.e., adopter) side of the market can now be arranged in accordance with the different stages of the product life cycle.

In the introduction stage, the majority of the adopter are innovators (Rogers, 2003). In the growth stage the user side of the market is made up out of users from the early adopter and

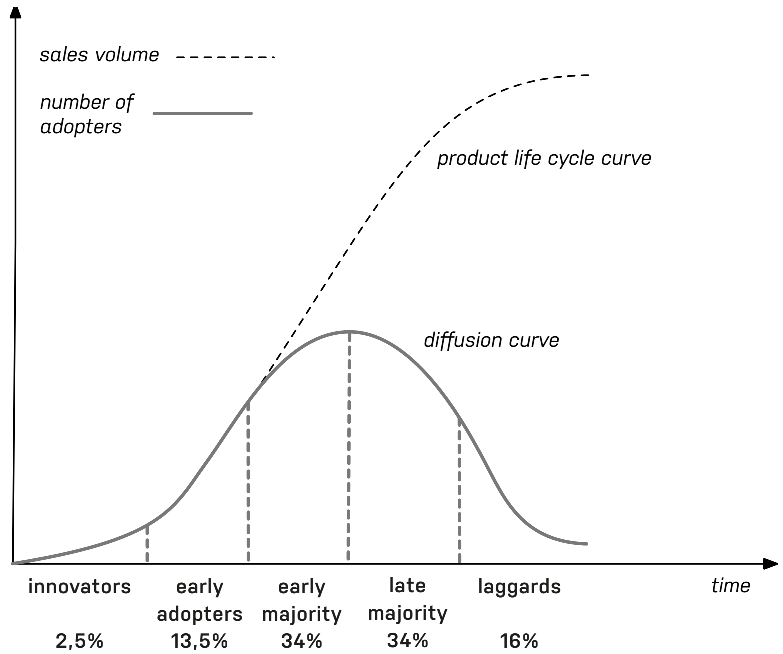


Figure E.3.5: Rogers' (2003) diffusion curve and adopter categories from figure E.3.2 merged with the product life cycle stages and key events from the classical product life cycle curve (Tellis & Crawford, 1981; Rink & Swan, 1979) from figure E.1.4. This makes clear how Rogers' (2003) adopter categories align with the four product life cycle stages, thus allowing the information on the user side of the market provided by Rogers' (2003) adopter categories characteristics to be combined with the information on the business side of the market for each product life cycle stage.

early majority categories. In the maturity stage the user side of the market consists of users from the late majority and laggard categories. This information on the characteristics of the user side of the market for each stage of the product life cycle of the market can, together with the information on the business side of the market for each stage of the product life cycle that is presented in the following section be used in sub-section 6.4.2 as input in determining the extent to which particular combinations of design directions and circular business model types can be expected to be successful in a particular product category life cycle stage.

Over time, *"improved technology, greater information dissemination and greater consumer purchasing power"* (Capon, 1985, p. 6) have shortened the overall product (sub-) category life cycles (Capon, 1985). Because of these shorter product (sub-)category life cycles, there is now often no time left to re-enter the market with a new product model after an earlier product model introduction has failed. By the time the new product model gets to market, the growth stage of the product (sub-)category is often already over (Capon, 1985). This increases the importance of entering the market with the right product design and the right business strategy the first time around (Capon, 1985). The fact that product (sub-)category life cycles are becoming shorter is also a potential barrier for product life extension, increasing the importance of adopting managing obsolescence as a business practice and design methodology. One of the questions that arises is how, for instance, a company introducing a new, longer lasting, product, can overcome these barriers. The heuristic framework for managing obsolescence as presented in sub-section 6.4.3 is intended to provide guidance to industrial

E

designers in developing answers to questions like these, for example by suggesting what design directions for preserving product integrity can contribute to a successful transition to (more) service based circular business model types that in theory are less sensitive to, and dependent on, continuous and rapid changes in the physical product component of the value proposition (Tukker, 2015, 2004, Tukker et al., 2006).

E.4 Dynamics and Characteristics of the Four Product Life Cycle Stages

In their seminal paper, "Patterns in Industrial Innovation", Abernathy and Utterback (1978) examined the development of markets, product (sub-) categories, and companies over time. Abernathy and Utterback (1978) concluded that *"changes in innovative pattern, production process, and scale and kind of production capacity all occur together in a consistent predictable way"* (p. 6). One of their main findings was that as the market for a new product (sub-) category develops and companies evolve from small start-ups or newcomers to established players, the focus of innovation shifts from radical product innovation to incremental process innovation (Abernathy & Utterback, 1978), as graphically presented in figure E.4.1, *"Patterns of innovative activity"*, adapted from Windrum and Birchenhall (1998, p. 111).

Abernathy and Utterback (1978) saw these shifts in innovative activity in a certain market as *"related to the development of a dominant product design, ... accompanied by heightened price competition and increased emphasis on process innovation"* (p. 6).

In much the same manner as was done with Rogers' (2003) diffusion curve and the product life cycle curve in figure E.3.5 in the previous section, the graph for the patterns of innovative activity from figure E.4.1 can be merged with the product life cycle curve from figure E.3.4, as shown in figure E.3.7.

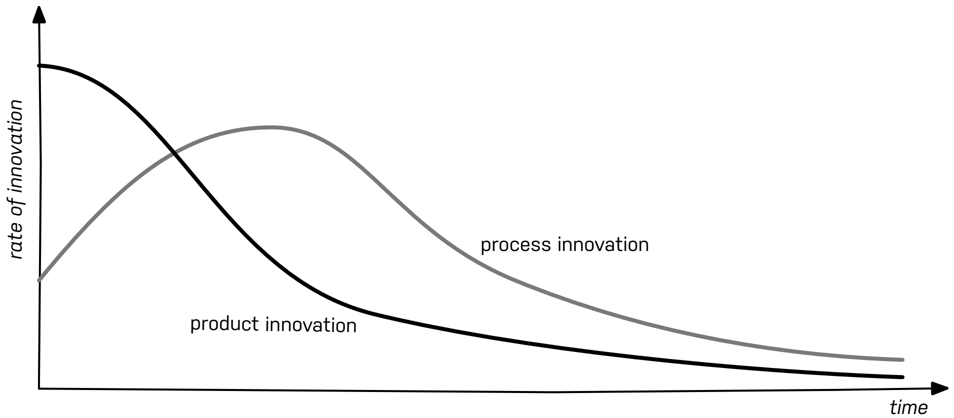


Figure E.4.1: Patterns of innovative activity, adapted from Windrum and Birchenhall, 1998, p. 111. As the market for a new product (sub-)category develops and companies evolve from small start-ups or newcomers to established players, the focus of innovation shifts from radical product innovation to incremental process innovation (Abernathy & Utterback, 1978).

From figure E.4.2 it can be seen how the *"changes in innovative pattern, production process, and scale and kind of production capacity"* (p. 6) observed by Abernathy and Utterback (1978) correspond to the various stages of the product life cycle. The findings of Abernathy and Utterback (1978), explaining and describing the specific business-economic and technological

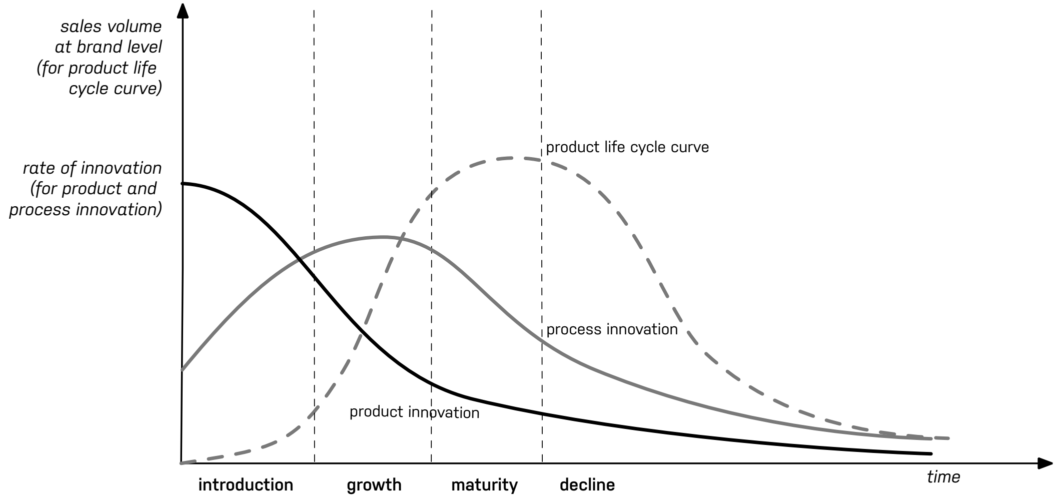


Figure E.4.2: Patterns of innovative activity graph (Windrum & Birchenhall, 1998; Abernathy & Utterback, 1978) from figure E.4.1, merged with the 'classic' (Rink & Swan, 1979) product life cycle curve from figure E.3.4. As the market for a new product (sub-)category develops and companies evolve from small start-ups or newcomers to established players, the focus of innovation shifts from radical product innovation to incremental process innovation (Abernathy & Utterback, 1978).

dynamics of a developing market, or product (sub-) category, over time can now be presented and discussed in the context of the four stages of the "classic" (Rink & Swan, 1979) product life cycle. Integrated in this manner with the product life cycle stages, the findings of Abernathy and Utterback (1975) provide guidance in determining business and product strategies for managing obsolescence.

We will now discuss the business-economic and technological developments as observed by Abernathy and Utterback (1978) that characterize the different product life cycle stages will be explained and described in more detail. We then present a summary of the business-economic and technological characteristics for the four the product life cycle stages in the form of a schematic overview that is used in conjunction with the schematic overview of table E.3.1 of the user (i.e., adopter) characteristics as input for our inferences of sub-section 6.4.2.

The Introduction Stage

According to Abernathy and Utterback (1978), the early stages of the development of a market for a new product (sub-) category is characterized by *"a diverse and responsive group of enterprises* [struggling] *against established units to enter industry"* (Abernathy & Utterback, 1978, p. 4). In the introduction stage, both product and market are ill defined (Capon, 1985; Utterback & Abernathy, 1975): *"most new industries in stage I* [i.e., the introduction and early growth stages] of a [product category] *life cycle are characterized by significant uncertainty regarding market size, product design, consumer tastes and technological constraints"* (Windrum & Birchenhall, 1998, p. 110). On the customer side, there is uncertainty about the performance of the new products and the overall viability of the new category. *"This typically leads to a variety of designs being offered, reflecting different firms' bets about the future"* (Windrum & Birchenhall, 1998, p. 110). At this stage, the business is focused on creating a new and innovative product (sub-) category that people can relate to and appreciate (Moon,

E

2005; Levitt, 1965), educating the market, i.e., *"getting consumers to try the product"* (Levitt, 1965, p. 4) and build brand identity (Moon, 2005). Innovation in companies is targeted at improving the product rather than the production process (Taylor & Taylor, 2012; Abernathy & Utterback, 1978). Sales volumes are typically low and show little progress (Levitt, 1965). In the introduction stage, the presence of (potential) competitors can however be helpful, because *"generally speaking, the more producers there are of a new product, the more effort* [and (financial) resources go] *... into developing a market for it"* (Levitt, 1965, p. 10). Especially in the introduction stage, "*customers may be fearful that the new product will not perform adequately"* (Capon, 1985, p. 4). Research shows that their fears might not be without ground, as new technology at its introduction often does not (yet) perform as well and reliably as the existing solutions it is attempting to replace (Sood & Tellis, 2005).

The Growth Stage

However, if the introduction is successful (which it too often is not (Levitt, 1965)) consumers start to become more familiar with and see the potential of the newly introduced product and the market starts to develop at an accelerated pace (Golder & Tellis, 2004). Potential competitors, now including those who earlier were not willing to run the risk of a failed introduction, equally start to recognize the potential and *"market expansion and redefinition result in frequent competitive improvements"* (Utterback & Abernathy, 1975, p. 641). From that moment on, it becomes important for a business to make customers or users *"prefer his brand"* (Levitt, 1965, p. 4) and capture and defend market share. Production capacity and distribution need to be ramped up as a failure to meet the rising demand can leave the door open for competitors (Capon, 1985). Newcomers, either independent start-ups or dedicated fledgling divisions from existing companies (Abernathy & Utterback, 1978), all with their own particular product and technology will now attempt to come up with the so-called *dominant design* (Taylor & Taylor, 2012, Kim, 2003; Anderson & Tushman, 1990; White, 1979; Abernathy & Utterback, 1978) for that particular product category (see figure E.3.4). At the (early) growth stage of a new product category, certain consistently more successful product models can begin to dominate a product sub-category or even spawn whole new product sub-categories (Windrum & Birchenhall, 1998). When this happens, the design and/or the technology employed in such a product model becomes the dominant design within a (new) sub-category. From the moment of its emergence, this dominant design will function as the archetype for all other products, e.g. product models that come after it in the same product sub-category. The dominant design often is that particular model that at the same time allows industry to adequately satisfy the needs of the greatest number customers and that can be manufactured in sufficient numbers against the lowest cost (Abernathy & Utterback, 1978).

This (technological) turbulence (Taylor & Taylor, 2012; Windrum & Birchenhall, 1998; Abernathy & Utterback, 1978; Utterback & Abernathy, 1975; Hofer, 1975) and general uncertainty are characteristic for the early growth stage of the product category lifecycle curve. On the customer side, there is uncertainty about the type of solution or system that will set the standard, i.e., the dominant design, potentially rendering customers' earlier investments obsolete. On the manufacturing side, *"technical problems with the production process, early product failure, or inability to expand production capacity to meet growing demand can retard market development"* (Capon, 1985, p. 4). Furthermore, there is the fear with pioneers that, if markets finally start to develop, they will be unable *"to fully satisfy market demand* [thus easing*] market entry for a newcomer"* (Capon, 1985, p. 4).

The Maturity Stage

Once a dominant design has been established for a particular product category or sub-category, the industry and product group tend to move towards and into the maturity stage where *"production systems, designed increasingly for efficiency, become mechanistic and rigid"* (Utterback & Abernathy, 1975, p. 641, the number of competitors goes down (Capon, 1985) but as the market is (close to being) saturated (Levitt, 1965) competition is intense (Taylor & Taylor, 2012; Moon, 2005; Abernathy & Utterback, 1978). Entry into the market for that particular product (sub-) category becomes difficult because of the *"cost economies and market positions achieved by entrenched competitors"* (Capon, 1985, p. 5). For a business active in a certain product (sub-)category, the position that the business has established at the end of the growth stage is of prime importance, for when a product (sub-)category is moving into maturity *"industry structures formed in early growth* [often] *become stabilized in this period...and market positions achieved by early maturity can often survive for many years"* (Capon, 1985, p. 5). According to Capon (1985), *"distribution is critical in maturity"* (p. 5) as *"differential advantage in the product is often difficult to achieve"* (p. 5). In the maturity stage, *"product characteristics are well understood"* (Abernathy & Utterback, 1978, p. 3), *"product variety tends to be reduced and the product becomes standardized"* (Utterback & Abernathy, 1975, p. 644) and *"competition is primarily on the basis of price"* (Abernathy & Utterback, 1978, p. 3), *"packaging and promotional strategies"* (Capon, 1985, p. 5). (Incremental) process innovation becomes more important than (radical) product differentiation (Capon, 1985; Abernathy & Utterback, 1978). Most sales are repeat or replacement purchases (Capon, 1985). As a result, changes in the actual product models often are minor. They are either cosmetic (e.g. *"styling and fashion"* (Levitt, 1965, p. 6) or based on the addition of secondary features in an attempt to stimulate replacement purchases or segment the market further to prolong the maturity stage. Unfortunately, this often leads to *"featuritis"* (Buschmann, 2010, p. 10), i.e., *"the tendency to trade functional coverage for quality - the more functions and the earlier they're delivered, the better. Reliability, performance, maintainability, and other qualities are postponed to 'when the functionality is stabilized"* (Buschmann, 2010, p. 10).

The maturity stage continues until the demand for the particular type of perceived use value provided by that product (sub-) category wanes (Capon, 1985) or is suddenly fulfilled in a (vastly) better manner by a new product (sub-) category with its own new dominant design and its own new market (Capon, 1985; Abernathy & Utterback, 1978). From that moment on, the product life cycle of the (old) product category will enter the stage of rapid or slow decline. According to Capon (1985) *"typically, decline is shorter when one product subcategory is replaced by another than when obsolescence of a product category is involved"* (p. 5).

The Decline Stage

The decline stage of a product (sub-)category is characterized by *"an environment of declining product demand where conditions make it very unlikely that all the plant capacity and competitors put in place during the industry's heyday will ever be needed"* (Harrigan & Porter, 1983, p. 1). The decline stage therefore often knows a fair amount of competition and determining a business strategy for this stage can be difficult and complex (Harrigan & Porter, 1983). It is the stage where the industry and product group tend to fall apart (Utterback & Abernathy, 1975). Under certain conditions (that will be discussed shortly) the decline stage can be a profitable stage for companies to operate in (Harrigan & Porter, 1983). However, when those conditions are not, or cannot be, met some businesses can decide to end their

E

activities in the declining product (sub-) category as quickly as possible and move into one or more other product (sub-)categories (e.g. practice divestiture and diversification (Harrigan, 1981; Hamermesh & Silk, 1979). For other businesses, it simply is not an option to abandon their activities in a declining product category, for example because they still derive too big a percentage of their revenue from that particular (sub-) category (Hamermesh & Silk, 1979), their *"exit barriers"* (Harrigan & Porter, 1983, p. 5) are too high or the product (sub-)category is central to their *"identity or image"* (Harrigan & Porter, 1983, p. 8). No matter how potentially difficult or complex, most businesses however will sooner or later have to address problems of competing in stagnant or declining product (sub-) categories, as *"it is a rare company that competes only in rapidly growing industries"* (Hamermesh & Silk, 1979, p. 14).

The decline stage of a product (sub-) category can play out according to a number of different scenarios because the decline stage scenario for the product (sub-)category is largely the result of the combined behaviour of the individual businesses involved in that particular product (sub-)category (Harrigan & Porter, 1983). The strategic choices and the resulting behaviour of the businesses in turn depend on the cause(s) for the falling demand and (Harrigan & Porter, 1983) and on the strategic and business-economic position at the onset of the decline. According to Harrigan and Porter (1983), causes for a decline in demand can be *"technological advances foster*[ing] *substitute products, often at lower cost or higher quality"* (p. 4), a shrinking customer group, *"buyers ...* [sliding] *into trouble"* (p. 4), *"changes in life-style, buyers' needs, or tastes"* (p. 4), rising *"cost of inputs or complementary products"* (p. 4), a reduced or a limited supply of natural resources. Knowing the specific causes for the experienced decline in demand in a product (sub-)category can be of great help in determining a business and/or product strategy for the decline stage (Harrigan & Porter, 1983).

An in-depth discussion of the intricacies of the decline stage from a business-economic and marketing point of view is deemed to fall outside the scope of this thesis, as it is well documented elsewhere in the literature (e.g., Harrigan & Porter, 1983; Harrigan, 1981; Hamermesh & Silk, 1979). As a ruling principle, Harrigan and Porter (1983) stated however, that *"successful companies should choose an end-game* [e.g. decline stage] *strategy rather than let one be chosen for them"* (p. 17) by their competitors. This can well be read as a plea in favour of integrating the management of obsolescence in business and/or product strategies.

When the options for the decline stage from a business perspective are put in a set of simple (binary) terms describing time and cost, e.g., "short" or "drawn out" and "profitable" or "non-profitable", this result in a matrix as shown in figure E.4.3. Though rudimentary and rather crude, the matrix from figure E.4.3 is deemed sufficient to illustrate and help explain the different options available to a business with a product in the decline stage of the product life cycle in the context of this thesis.

In planning a business strategy for the decline stage, positions in the upper left quadrant of figure E.4.3, "drawn out & non-profitable", are to be avoided whenever possible (Harrigan & Porter, 1983; Hamermesh & Silk, 1979). Positions in the lower left quadrant, "short & non-profitable", are preferable to "drawn out & non-profitable", but clearly still inferior to positions in the lower and upper right quadrants, "short & profitable" and "drawn out & profitable" (Harrigan & Porter, 1983; Hamermesh & Silk, 1979). Depending on the broader long-term strategy of a company (often comprising multiple product (sub-) categories), desirable outcomes either lie in the lower or the upper right quadrant (Harrigan & Porter, 1983; Hamermesh & Silk, 1979).

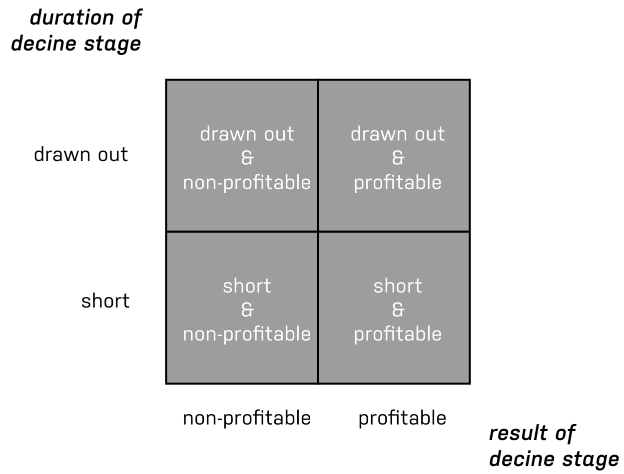


Figure E.4.3: The options for the duration and result of the decline stage from a business perspective put in the simplest of (binary) terms (i.e, "short" or "drawn out" and "non-profitable" or "profitable") in order to illustrate and help explain the different options available to a business with a product in the decline stage of the product category or industry life cycle.

Claiming *"the best course is anticipation of the decline"* (p. 17), Harrigan & Porter (1983) presented four actions a business could take already during the maturity stage that would leave it in a better strategic and business-economic position in the decline stage. These four actions are listed below as they provide additional guidelines for determining business and/or product strategies and selecting combinations of design directions and circular business model types and for preserving product integrity in preparation of (and into) the decline stage of the product category life cycle:

- Minimize investments or other actions that will raise exit barriers unless clearly beneficial to overall corporate strategy.
- Increase the flexibility of assets so that they can accept different raw materials or produce related products.
- Place strategic emphasis on market segments that can be expected to endure when the industry is in a state of decline.
- Create customer-switching costs *[e.g. make it difficult or costly for customers to abandon your product]* in these segments (Harrigan & Porter, 1983, p. 17).

Harrigan (1981) took this planning for the inevitable decline stage a step further by suggesting that businesses *"will want to plan their exits at the time of entry"* (p. 322) into a product (sub-)category. Although acting here at a different level, the principle underlying this idea, e.g. *beginning with the end in mind*, clearly reflects the basic concept of managing obsolescence.

The above actions, suggested by Harrigan and Porter (1983), primarily serve to keep the position of a business out of the lower and upper left, i.e., "non-profitable", decline stage quadrants from figure E.4.3. The second recommended action, regarding increased flexibility of assets, can however also contribute to a "short & profitable" decline stage at business level (either forced by competitor behaviour or voluntary (Harrigan & Porter, 1983)) as it facilitates the swift (internal) reallocation or (external) sale of assets (Harrigan & Porter, 1983; Harrigan, 1981).

Under certain conditions, it is possible for businesses to move to the upper right "drawn out & profitable" quadrant of figure E.4.3. The first condition for thriving in the upper right quadrant is that there need to be *"remaining demand pockets"* (Harrigan & Porter, 1983, p. 5) with a *"favourable structure"* (Harrigan & Porter, 1983, p. 5) in the declining product (sub-) category. Remaining demand pockets are the *"growth segments"* (Hamermesh & Silk, 1979, p. 5) or product sub-categories that remain in demand despite the decline in demand for the overall product category or industry. The structure of these demand pockets is favourable *"if the buyers in the remaining demand pockets are price insensitive"* (Harrigan & Porter, 1983, p. 6) and *"customers are immune to substitute products and brand loyal"* (Harrigan & Porter, 1983, p. 5), or *"have little bargaining power"* (Harrigan & Porter, 1983, p. 6). The second condition for thriving in the upper right quadrant is that a business needs to possess the necessary competitive strengths for competing in those remaining demand pockets (Harrigan & Porter, 1983).

Hamermesh and Silk (1979) provided some *"strategies for success"* (p. 4) for businesses that are competing in stagnant product (sub-) categories, i.e., product (sub-)categories that are in the late mature or early decline stage. Again, these are presented below as they provide additional guidelines for determining business and/or product strategies and selecting combinations of design directions and circular business models for preserving product integrity when managing obsolescence of a product that is designed to be introduced into, or is likely to during its lifetime enter, the decline stage of the product category life cycle:

- *"Concentrate on growth segments"* (Hamermesh & Silk, 1979, p. 5). Effectively focusing on growth segments requires detailed information on the industry and on (potential) customers;
- Compensate for lost product sales by expanding the service component of the business (Hamermesh & Silk, 1979).;
- Pursue *"high-quality, innovative products"* (Hamermesh & Silk, 1979, p. 7, i.e., manufacture and market products that distinguish themselves from alternative products on the market on the basis of their functional and aesthetic properties, not (solely) on the basis of price;
- Constantly pay attention to cost reduction; whereby *"the most common way to achieve lower cost seems to be by improving the manufacturing process"* (Hamermesh & Silk, 1979, p. 9). This can for example be achieved by *"high degrees of specialization and automation"* (Hamermesh & Silk, 1979, p. 9).

The four strategies presented by Hamermesh and Silk (1979) indicate potential opportunities for particular combinations of design directions and circular business model types for preserving product integrity for products that are designed to be introduced in an industry that is in decline.

Overview of Business Foci and Properties of the Four Industry Life Cycle Stages
An overview summarizing the business foci and properties for each of the different product category life cycle stages according to the literature and discussed in the previous paragraphs is presented in table E.4.1.

Changing Product Category Life Cycle Stages by Jumping Between Curves
Although a single company generally cannot affect the product (sub-)category life cycle (Capon, 1985), the literature does provide examples of marketing strategies that companies can apply to affect the stage that a newly designed product will end up in.

To reduce the time from the introduction to the growth stage of a newly introduced product category, Moon (2005) for example proposed a marketing strategy by the name of *"stealth positioning"* (p. 2): "[Associate] *a 'tainted' product with a category consumers embrace"* (p. 5) to acclimatize customers to a technologically intimidating or not-yet-refined new offering. Sony for example used this approach when they presented their barely functional house-hold robot AIBO as a quirky pet (Moon, 2005). According to Moon (2005), stealth positioning is especially suited to technology products.

To postpone the onset of the decline stage of an industry life cycle, Moon (2005) for example proposed the marketing strategies of *"reverse positioning"* (p. 2) and *"breakaway positioning"* (p. 2).

Moon (2005) described *reverse positioning* as: *"By stripping away attributes consumers expect in a mature product, and adding some surprising new ones, companies can shift a product backward from maturity into the growth phase"* (p. 5). As an example, Moon (2005) presented jetBlue (2017), a North American airline that eliminated first-class seating and complimentary in-flight meals while offering leather seats and extra legroom (Moon, 2005). Reverse positioning is especially suited to products with a large service component (Moon, 2005).

Moon (2005) described *breakaway positioning* as: *"by combining features of products in distinctly different categories"* (p. 5) and associating their product with a radically different category *"companies can reposition a mature product for growth"* (p. 5). As an example of breakaway positioning, Moon (2005) presented the Swiss watch manufacturer Swatch (Swatch, 2018) who marketed its watches as fashion accessories, instead of as fine jewellery (Moon, 2005). According to Moon (2005), breakaway positioning is especially suited to packaged goods.

All three marketing strategies as proposed by Moon (2005) in essence serve to change the *"positioning"* (Ries & Trout, 1986, p. 1) of, or *"how customers mentally categorize"* (Moon, 2005, p. 2), products. They are mentioned here separately because they are fundamentally different from other approaches as for example proposed by Harrison and Porter (1983) and Hamermesh and Silk (1979). The approaches as proposed by Harrison and Porter (1983) and Hamermesh and Silk (1979) served to speed up or slow down the progression of a product along the product life cycle curve in one product (sub-) category. The marketing strategies proposed by Moon (2005) however, provide businesses with a way to move their product from a less favourable life cycle stage in one product (sub-)category to a more favourable life cycle stage in a different product (sub-)category.

	Introduction	Growth	Maturity	Decline	
				Drawn out & profitable	***Short & profitable***
Business focus	Educate the market and build brand identity (Moon, 2005)	Refine the product and build brand preference (Moon, 2005)	Augment and differentiate the product and build brand reputation (Moon, 2005)	Phase out weak models, reduce cost and milk the brand (Moon, 2005)	Divest and diversificate (Harrigan, 1981)
Competition	Limited (Moon, 2005; Capon, 1985; Levitt, 1965)	Growing (Moon, 2005; Capon, 1985; Levitt, 1965)	Intense (Moon, 2005; Capon, 1985; Levitt, 1965)	Fading (Moon, 2005), but initially substantial (Capon, 1985; Harrigan & Porter, 1983)	Fading (Moon, 2005), but substantial (Capon, 1985; Harrigan & Porter, 1983)
Market segmentation	Latent (Moon, 2005)	Emerging (Moon, 2005)	Fragmented (Moon, 2005)	Eroding (Moon, 2005)	Eroding (Moon, 2005)
Innovation focus	Product (Abernathy & Utterback, 1978)	Product (Abernathy & Utterback, 1978	Process (Abernathy and Utterback, 1978)	Product & process (Hamermesh and Silk, 1979)	n.a.
Innovation rate	Medium to high (Capon, 1985; Abernathy & Utterback, 1978)	High (Abernathy & Utterback, 1978)	High (Abernathy & Utterback, 1978)	Low (Hamermesh & Silk, 1979)	n.a.
Primary business challenges	Create a new and innovative product (sub-) category that people can relate to and can (learn to) appreciate (Moon, 2005; Levitt, 1965)	Create or copy the dominant design (Windrum & Birchenhall 1998; Capon, 1985; Abernathy & Utterback, 1978; Levitt, 1965)	Fend off competition and increase profitability by reducing cost through process innovation (Capon, 1985; Abernathy & Utterback, 1978)	Seek out and focus on growth segments (Hamermesh & Silk,1979) or favourable pockets of demand (Harrigan & Porter, 1983)	Sell off assets in a timely and profitable manner (Harrigan, 1981)
	Devise and deploy strategies to "get consumers to try the product'" (Levitt, 1965, p. REF)	Devise and deploy strategies to get consumers to "prefer [the] brand" (Levitt, 1965, p. REF)	Maintain and expand distribution (Capon, 1985; Levitt, 1965)	Create "high-quality, innovative products" (Hamermesh & Silk, 1979, p. REF)	
		Handle the accelerating demand (production and distribution) (Capon, 1985; Abernathy & Utterback, 1978)	Retain or expand market share by devising and deploying strategies (for example pricing structures, product model changes or additional services) (Capon, 1985; Hamermesh & Silk, 1979; Levitt, 1965)	Increase profitability by reducing cost (specialization and/or automation) (Hamermesh & Silk, 1979)	
Secondary business challenges	Reduce time to*, and prepare the business for, the growth stage (Harrigan, 1981; Levitt, 1965;)	Prepare the business for the maturity stage (Harrigan, 1981; Levitt, 1965)	Postpone**and prepare the business for, the onset of the decline stage (Harrigan &Porter, 1983; Harrigan, 1981; Levitt, 1965))		

*Table E.4.1: An overview of business foci and properties for each of the different life cycle stages of a product (sub-) category as indicated by the literature. Notes: *e.g., through "stealth positioning" (Moon, 2005, p. 2), **e.g., through "reverse positioning" (Moon, 2005, p. 2) or "breakaway positioning" (Moon, 2005, p. 2).*

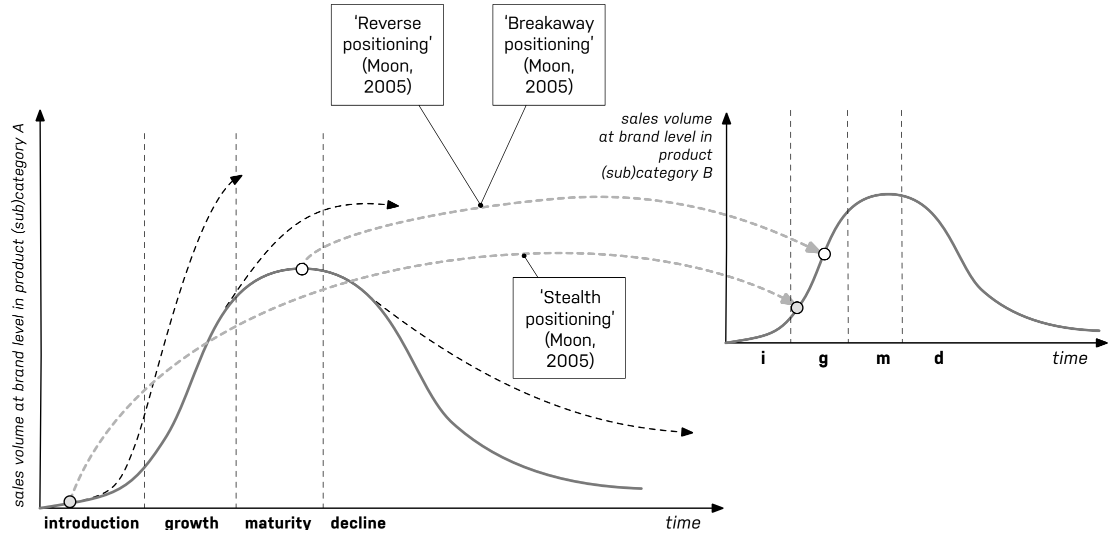


Figure E.4.4: The goals the companies have for their products (or brand) in each of the different life cycle stages of a product (sub-) category are visualized by the black curved arrows in dotted lines. The grey curved arrows represent the repositioning strategies as proposed and by Moon (2005), shifting, e.g. repositioning (Ries & Trout, 1986), a product from product (sub-) category A to a more favourable life cycle stage in product (sub-)category B.

The black curved arrows in dotted lines in figure E.4.4 visualize the goals the companies have for their products (or brand) in each of the different life cycle stages of a product (sub-) category. The grey curved arrows represent the repositioning (Ries & Trout, 1986) strategies as proposed by Moon (2005).

REFERENCES APPENDIX E: THE PRODUCT LIFE CYCLE AND RELATED CONCEPTS

Abell, D.F. (1980). *Defining the Business: The Starting Point of Strategic Planning*. Englewood Cliffs, NJ, USA: Prentice Hall, Inc.

Abernathy W. J., & Utterback J. M. (1978). Patterns of Innovation in Technology. *Technology Review 80*, 40-47.

Anderson, P., & Tushman, M. L. (1990). Technological discontinuities and dominant designs: A cyclical model of technological change. *Administrative science quarterly*, 604-633.

Apple (2018). Apple Inc. company website: www.apple.com

Bass, F. M. (1969). A New Product Growth for Model Consumer Durables. *Management Science, 15*(5), Theory Series, 215-227.

Bass, F. M. (2004). Comments on "a new product growth for model consumer durables the bass model". *Management science, 50*(12_supplement), 1833-1840.

Buzzell, R. (1966). Competitive Behavior and Product Life Cycles. In Wright, J. & Goldstucker, J. (Eds.), *New Ideas for Successful Marketing*. Chicago, IL, USA: American Marketing Association.

Capon, N. (1985). *The Product Life Cycle*. Document 9-579-072. Harvard, U.S.A.: Harvard Business School.

Dean, J., 1950. Pricing Policies for New Products, *Harvard Business Review, 28*, 45-53.

Dhalla, N. K., & Yuspeh, S. (1976). Forget the Product Life Cycle Concept. Retrieved January 20th, 2018 from: https://hbr.org/1976/01/forget-the-product-life-cycle-concept. (PDF web reprint from *Harvard Business Review, 54*, 102–112).

Day, G. S. (1981). The product life cycle: analysis and applications issues. *The Journal of Marketing*, 60-67.

Enis, B. M., LaGarce, R., & Prell, A. E. (1977). Extending the Product Life Cycle. *Business Horizons, 20*, 46-56.

Golder, P. N. & Tellis, G. J. (2004). Growing, Growing, Gone: Cascades, Diffusion, and Turning Points in the Product Life Cycle. Marketing Science, 23(2), 207-218.

Hamermesh, R. E., & Silk, S. B. (1979). How to Compete in Stagnant Industries. Retrieved November 26th, 2017 from https://hbr.org/1979/09/how-to-compete-in-stagnant-industries (PDF web reprint from *Harvard Business Review, 57*(5), pp. 161-168.

Harrigan, K. R., & Porter, M. E. (1983). End-Game Strategies for Declining Industries. Harvard Business Review, Vol. 61, No. 4, pp. 111-120.

Hofer, C.W., & Schendel, D. (1978). Strategy Formulation: Analytical Concepts. St. Paul, MN, USA: West Publishing Company.
Holak, S. L., & Y.E. Tang, Y. E. (1990). Advertising's Effect on the Product Evolutionary Cycle. Journal of Marketing, 54(3), 16-29.
JetBlue (2018). JetBlue company website: www.jetblue.com
Kim, B. (2003). Managing the transition of technology life cycle. *Technovation, 23*, 371–381.
Kotler, P. (1984). *Marketing Management* (5th ed.), London, UK: Prentice/Hall International.
Levitt, T. (1965). Exploit the product life cycle. Retrieved November 26th, 2017 from https://hbr.org/1965/11/exploit-the-product-life-cycle (PDF web reprint from *Harvard business review*, *43*, 81-94).
Moon, Y. (2005). Break Free from the Product Life Cycle. Retrieved December 20th, 2017 from: https://hbr.org/2005/05/break-free-from-the-product-life-cycle (PDF web reprint from *Harvard Business Review, 83*(5), 86-94). *Harvard Business Review*, May issue.
Peres, R., Muller, E., & Mahajan, V. (2009). Innovation diffusion and new product growth models: A critical review and research directions. *International Journal of Research in Marketing, 27*, 91-106.
Polli, R. & Cook, V. (1969). Validity of the Product Life Cycle. *The Journal of Business, 42*(4), 385-400.
Ries, A., & Trout, J. (1986). *Positioning, the Battle for Your Mind.* New York, U.S.A.: Warner Books.
Rink, D. R., & Swan, J. E. (1979). Product life cycle research: A literature review. *Journal of business Research, 7*(3), 219-242.
Rogers, E. M., 1958. Categorizing the Adopters of Agricultural Practices. *Rural Sociology, 23*(4), 346-354.
Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.) New York, NY, U.S.A.: The Free Press.
Ryan, B., & Gross, N. C. (1943). The diffusion of hybrid seed corn in two Iowa communities. *Rural sociology, 8*(1), 15.
Sood, A. & Tellis, G.J. (2005). Technological Evolution and Radical Innovation. *The Journal of Marketing, 69*(3), 152-168.
Swatch (2018). Swatch company website: www.swatch.com.
Taylor, M., & Taylor, A. (2012). The technology life cycle: Conceptualization and managerial implications. *International journal of production economics, 140*(1), 541-553.
Tellis, G., & Crawford, C.M. (1981). An Evolutionary Approach to Product Growth Theory. *The Journal of Marketing, 45*(4), 125-132.
Tukker, A. (2004). Eight Types of Product– Service System: Eight Ways to Sustainability? Experiences from Suspronet. *Business Strategy and the Environment 13*, 246–260.
Tukker, A. (2015). Product services for a resource-efficient and circular economy - a review. *Journal of Cleaner Production, 97*, 76-91.
Tukker, A., Van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In A. Tukker and U Tischner (Eds.), N*ew Business for Old Europe - Product-service development, competitiveness and sustainability* (pp. 22-34). Sheffield, UK: Greenleaf Publishing Ltd.
Utterback, J. M. and W. J. Abernathy (1975). A Dynamic Model of Process and Product Innovation. OMEGA International Journal of Management Science, 3(6), 639-656.
White, G. R. (1979). Management criteria for effective innovation. *IEEE Transactions on Professional Communication*, (2), 77-82.
Windrum, P., & Birchenhall, C. (1998). Is product life cycle theory a special case? Dominant designs and the emergence of market niches through coevolutionary-learning. *Structural Change and Economic Dynamics*, *9*(1), 109-134.
Wood, L. (2000). Brands and brand equity: definition and management. *Management Decision, 38*(9), 662 – 669.

APPENDIX F: COMPANY INTERVIEW GUIDE DIAGRAM

The diagram from figure F.1 below was used to offer initial structure for the company interviews. The diagram contains the nine business model building blocks from Osterwalder and Pigneur's (2010) business model canvas and includes a condensed version of the detailed options for each of the building blocks as offered by Osterwalder and Pigneur (2010) for each building block. In the center, the diagram contains an early version of the design strategies for preserving product integrity as they were gathered from the literature (see chapter 2).

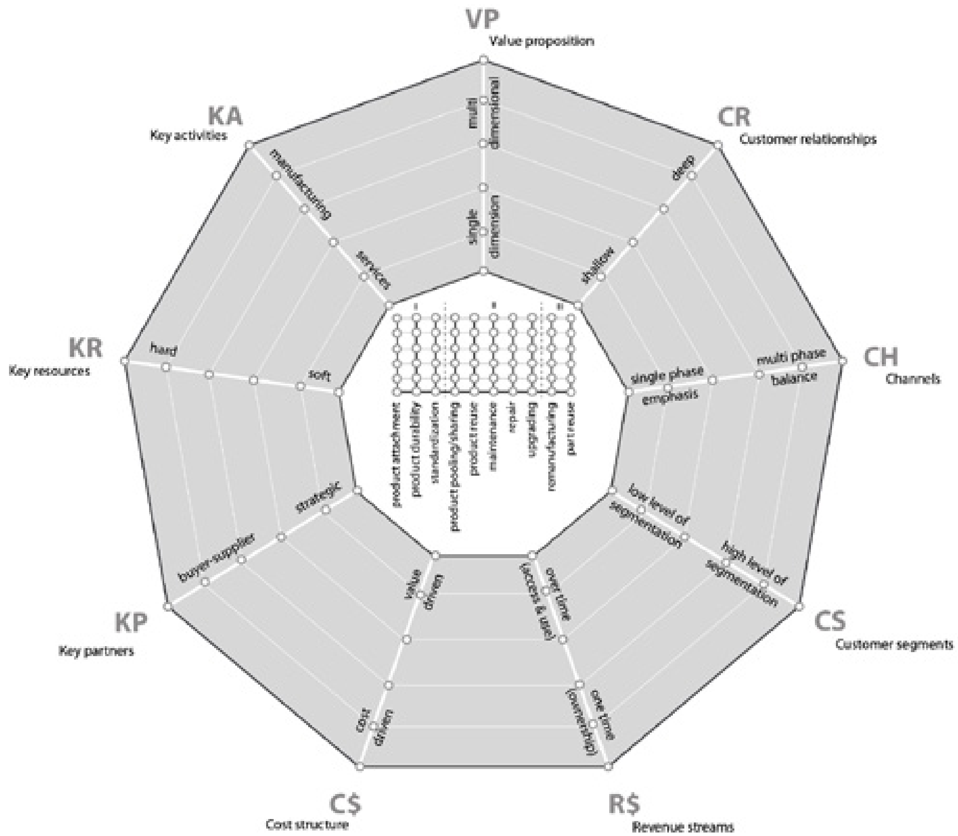


Figure F.1: The diagram that was used to guide the interviews with company representatives.

Based on the diagram shown in figure F.1, the respondents were (in different order and phrasing, depending on the flow of the interview) asked about the workings of their respective companies with respect to the nine building blocks. The respondents were also asked whether their respective companies applied interventions for extending product lifetimes as shown in the center of the diagram.

F

REFERENCES APPENDIX F: COMPANY INTERVIEW GUIDE DIAGRAM
Osterwalder, A., & Pigneur, Y. (2010). *Business Model Generation*. Hoboken, NJ, USA: John Wiley & Sons.

Welke ontwerpmethodologie kan industrieel ontwerpers helpen producten te ontwerpen die zijn toegesneden op bedrijfsmodellen voor het creëren, leveren en te gelde maken van waarde op basis van lange en verlengde productlevensduren in een circulaire economie?

SAMENVATTING

Deze dissertatie beschrijft de ontwikkeling van een ontwerpmethodologie die industrieel ontwerpers kan helpen om producten met een lange of verlengde levensduur te ontwerpen ter ondersteuning van een circulaire economie en is geschreven vanuit het perspectief van een industrieel ontwerper.

HOOFDSTUK 1: INLEIDING (ENG.: *CHAPTER 1: INTRODUCTION*). Materiële hulpbronnen zijn van levensbelang voor de industriële economie. Sinds het begin van de Industriële Revolutie is de snelheid waarmee de economie natuurlijke hulpbronnen verbruikt en afval produceert door de productie en consumptie van producten gestaag toegenomen tot een, vanuit milieu (vervuiling) en economisch (aanbod) oogpunt bezien, kritiek niveau. Er zijn veel verschillende opties om het verbruik van hulpbronnen en de productie van afval te verminderen bedacht en uitgeprobeerd, met wisselend succes. Deze varieerden van het instellen van beleids- en wettelijke maatregelen en initiatieven om de markt te prikkelen tot pogingen om het gedrag van consumenten te beïnvloeden. De meest veelbelovende optie, zowel vanuit ecologisch- als economisch perspectief, om de snelheid waarmee de economie natuurlijke hulpbronnen verbruikt te beperken, is het reduceren – en beter nog minimaliseren – van de stroom van niet-duurzame energie en (natuurlijke) hulpbronnen door de economie. Dit kan bijvoorbeeld door op systematische wijze, en bij voorkeur keer op keer, te proberen zoveel mogelijk van de door economische processen aan (natuurlijke) hulpbronnen toegevoegde waarde te behouden. Het is dit idee dat aan de basis ligt van het circulaire economie concept; een concept dat in de afgelopen jaren omarmd is door de Europese Commissie en snel opgang maakt in zowel de wetenschappelijke gemeenschap als de maatschappij in bredere zin. Het tweeledig doel van een circulaire economie is om de energie -en materiaalstromen in en uit het economische systeem te beperken tot een niveau dat getolereerd en – in principe – onbeperkt in stand gehouden kan worden door de natuur en tezelfdertijd de capaciteit van het economische systeem om welvaart te creëren te beschermen. Een circulaire economie streeft ernaar om de economische en ecologische waarde van materialen zo lang mogelijk te bewaren door materialen zo lang mogelijk in het economische systeem te houden. Dit gebeurt bij voorkeur door de nuttige levensduur van de producten waar ze deel van uitmaken te verlengen. Wanneer levensduurverlenging op productniveau niet meer mogelijk is, hetzij vanwege economische of ecologische redenen, worden producten vervolgens teruggevoerd in het productieproces, zodat de materialen waaruit ze zijn opgebouwd opnieuw gebruikt kunnen worden. Het concept 'afval' bestaat niet meer in een circulaire economie omdat producten en materialen – in principe - eindeloos worden (her)gebruikt. Hieruit volgt dat levensduurverlenging van producten – niet *in plaats van*, maar *in aanvulling op* hergebruik van materialen – en het vermogen om economische meerwaarde te creëren op basis van de lange of verlengde levensduur van producten een essentiële rol spelen in een circulaire economie. Industrieel ontwerpen heeft de potentie om een significante rol te spelen in het realiseren van de doelen van een circulaire economie omdat het ontwerp van een product niet alleen de eigenschappen van het tastbare product bepaalt maar ook de structuur van de totale waardeketen beïnvloedt.

Deze dissertatie behoort tot de wetenschappelijke discipline van ontwerponderzoek en richt zich, binnen deze grotere discipline, op het domein van duurzaam ontwerpen. Dat wil zeggen, dát segment van het vakgebied industrieel ontwerpen, dat bij het bedenken en ont-

NL

wikkelen van producten en systemen doelbewust de extra verantwoordelijkheid op zich neemt om economische, ecologische en sociale aspecten met elkaar in balans te brengen (Charter & Tischner, 2001), met het einddoel om menselijk welzijn op lange termijn te ondersteunen en te bewaken.

Het vakgebied van duurzaam ontwerpen vindt haar oorsprong in wat 'eco-design' genoemd wordt. Eco-design is de systematische integratie van milieuaspecten in het ontwerp van een product met het doel om de milieubelasting van dat product, bezien over de gehele productlevenscyclus, te verminderen.

Naarmate het gebied van duurzaam ontwerpen zich ontwikkelde, werd de reikwijdte ervan geleidelijk groter. Waar eco-design in de eerste plaats te maken heeft met materiaal- en energiestromen, heeft duurzaam ontwerpen bijvoorbeeld ook aspecten als sociale duurzaamheid opgenomen. Omdat het proefschrift een materiaalstromen-perspectief op de circulaire economie inneemt, vergelijkt het productontwerpen voor een circulaire economie met eco-design (maar niet met duurzaam productontwerpen in bredere zin). Eco-design wordt algemeen erkend als onderdeel van het domein van duurzaam productontwerpen en is goed ontwikkeld. Het biedt industrieel ontwerpers een ontwerpmethodologie, d.w.z. een reeks leidende principes, eco-designstrategieën en methoden, voor het systematisch integreren van milieuaspecten in productontwerp met het doel de milieuprestaties van een product, bezien over de gehele productlevenscyclus, te verbeteren.

Dit proefschrift stelt echter dat er een fundamenteel onderscheid moet worden gemaakt tussen eco-design en productontwerpen voor een circulaire economie, ook wel circulair productontwerpen genoemd, en dat dit betekent dat circulair productontwerpen een nieuwe, of op zijn minst een aangepaste, ontwerpmethodologie vereist.

Het belangrijkste verschil tussen eco-design en circulair productontwerpen is van methodologische aard. De huidige ontwerpmethodologie (leidende principes, strategieën en methodes) voor productlevensduurverlenging zoals voorgesteld door eco-design is geworteld in het hier en nu (de lineaire economie). De huidige ontwerpmethodologie is gericht op het verminderen van (de mileueffecten van) bestaande problemen (bijvoorbeeld afval als een bijproduct van het creëren van welvaart) en is als zodanig een voorbeeld van wat in de literatuur bekend staat als een *relatieve* benadering van duurzaamheid. Maar hoe kunnen industrieel ontwerpers nu echt duurzame of circulaire innovaties bedenken als de huidige methodes alleen maar leiden tot optimalisatie van wat er al is? Circulair productontwerpen daarentegen begint bij een geïdealiseerde eindtoestand (Faber, Jorna & Van Engelen, 2005) (bijvoorbeeld het genereren van welvaart zonder afval te creëren) en probeert middels systematisch itereren de kloof tussen daar en hier te dichten. Als zodanig is het een voorbeeld van wat in de literatuur bekend staat als een *absolute* benadering van duurzaamheid. Hoewel absolute benaderingen door velen als utopisch, onpraktisch en onnodig normatief werden beschouwd, zouden ze om twee redenen voordelen kunnen bieden boven, en complementair kunnen zijn aan, relatieve benaderingen van duurzaamheid.

De eerste is dat, omdat absolute benaderingen ideeën van een ideale staat impliceren (in dit geval een circulaire economie zonder afval als een ideale staat), ze industrieel ontwerpers kunnen uitdagen om naar zo'n ideale staat te streven, waardoor een bredere oplossingsruimte ontstaat en de waarschijnlijkheid om innovatieve oplossingen te vinden toeneemt. Dit zou kunnen leiden tot nieuwe oplossingen die misschien niet evident zijn of als haalbaar worden beschouwd wanneer het probleem wordt bekeken vanuit een relatief, in dit geval lineair, economisch perspectief, maar die slechts dan zichtbaar worden wanneer het probleem in een andere en bredere (sociaaleconomische) context mag worden beschouwd. De tweede reden is dat, vanwege het verbrede perspectief, een absolute benadering industrieel ontwerpers kan helpen onbedoelde nadelige effecten van hun interventies te vermijden die zouden kunnen optreden als onderliggende, en vaak meer systematische, problemen niet worden aangepakt.

In de afgelopen zes decennia heeft het eco-designveld bijvoorbeeld de levensduurverlenging van producten voornamelijk ingekaderd vanuit een oogpunt van efficiënt gebruik van hulpbronnen, waarbij grotendeels voorbij is gegaan aan de belangrijke rol die bedrijfseconomische implicaties spelen in het kader van het concept van een circulaire economie. Ondanks haar nut voor wat betreft het verminderen van de milieueffecten van producten, heeft de aanpak van eco-design de interactie tussen (het ontwerp van) tastbare producten met een lange levensduur en hun bedrijfseconomische context grotendeels buiten beschouwing gelaten. Als een gevolg van deze tamelijk nauwe manier van inkaderen van productlevensduurverlenging – dat wil zeggen, een benadering vrijwel uitsluitend gericht op fysieke producten en efficiënt gebruik van hulpbronnen – is nauwelijks aandacht besteed aan de ontwikkeling van een ontwerpmethodologie die expliciet gericht is op het benutten van de *interacties* tussen (het ontwerp van) fysieke producten en hun bedrijfseconomische context als middel om de levensduur van producten systematisch te verhogen, laat staan te optimaliseren. Met de recente toename van de aandacht voor het concept van de circulaire economie en de adoptie ervan door de EU, is het hieruit resulterende gebrek aan kennis op dit gebied sterker voelbaar geworden en dient derhalve te worden aangepakt, omdat het vermogen om gebruik te maken van de bovengenoemde interacties in hoge mate bepalend is voor het economische en ecologische succes van het concept van de circulaire economie.

Vanuit een absoluut perspectief op duurzaamheid op het concept van de circulaire economie, wil dit proefschrift daarom een ontwerpmethodiek ontwikkelen voor het ontwerpen van producten met een lange en/of verlengde productlevensduur in een circulaire economie met de bedoeling om deze kenniskloof te helpen dichten. Dienovereenkomstig luidt de centrale onderzoeksvraag van dit proefschrift:

"Welke ontwerpmethodologie kan industrieel ontwerpers helpen producten te ontwerpen die zijn toegesneden op bedrijfsmodellen voor het creëren, leveren en te gelde maken van waarde op basis van lange en verlengde productlevensduren in een circulaire economie?"

Om tot een antwoord op de bovenstaande onderzoeksvraag te komen, is het proefschrift onderverdeeld in twee delen, waarin vervolgens een aantal deelonderzoeksvragen worden behandeld. Het eerste gedeelte, hoofdstuk 2 tot en met hoofdstuk 4, heeft tot doel een theoretisch kader te scheppen voor de ontwikkeling van een nieuwe ontwerpmethodologie die wordt gepresenteerd in het tweede gedeelte, hoofdstuk 5 tot en met hoofdstuk 6. (Omdat de dissertatie, vanwege het interdisciplinaire karakter van het onderwerp, literatuur uit meerdere wetenschappelijke domeinen raadpleegt en beoordeelt, is na de hoofdtekst een reeks bijlagen toegevoegd om lezers die bekend zijn met concepten uit sommige van deze domeinen, maar minder met concepten uit andere domeinen, van achtergrondinformatie te voorzien.)

HOOFDSTUK 2: BEHOUDEN VAN PRODUCTINTEGRITEIT (ENG.: *CHAPTER 2: PRESERVING PRODUCT INTEGRITY*) beoogt een antwoord te bieden op deelonderzoeksvraag A: "Hoe kan de levensduurverlenging van een product in een circulaire economie worden gedefinieerd binnen de context van industrieel ontwerpen?" Het hoofdstuk onderzoekt en bespreekt de literatuur die betrekking heeft op de verschillende staten waarin grondstoffen kunnen verkeren en op de diverse interventies voor productlevensduurverlenging. Het biedt een uitgebreid overzicht van de belangrijkste concepten en termen die relevant worden geacht voor industrieel ontwerpers bij het ontwerpen van producten bedoeld voor een lange en verlengde productlevensduur in een circulaire economie. Dit hoofdstuk definieert productlevensduur in termen van overbodigheid (Eng.: *obsolescence*), waardoor het duidelijk maakt dat de levensduur van een product niet slechts een technische kwaliteit is die middels ontwerpen aan een producten kan worden toegekend, maar ook wordt beïnvloed door niet tastbare factoren zoals gebruikersgedrag en bredere sociaal-culturele invloeden. Gezien deze vele factoren die de levensduur van het product kunnen beïnvloeden, stelt hoofdstuk 2 dat industrieel ontwerpers geen producten met een lange of verlengde levensduur kunnen ontwerpen, maar producten alleen kunnen voorzien van *een potentieel voor* een lange of verlengde levensduur. De mate waarin dit potentieel daadwerkelijk wordt gerealiseerd, wordt in belangrijke mate bepaald door factoren anders dan het ontwerp van de fysieke producten of systemen, zoals de sociaaleconomische context van het product (bijvoorbeeld het bedrijfsmodel waarin het product is ingebed).

Verder presenteert hoofdstuk 2 nieuwe definities van interventies voor productlevensduurverlenging en introduceert het nieuwe concepten zoals 'rondstof' (Eng.: *presource*), 'herwinningshorizon' (Eng.: *recovery horizon*) en 'lekkage' (Eng.: *leakage*) om tegemoet te komen aan het feit dat het concept 'afval' in een circulaire economie niet langer bestaat. Door deze interventies te ordenen in de volgorde zoals die wordt voorgesteld door Stahel's (2010) *Inertia Principle*, kan het hoofdstuk een nieuwe typologie ontwikkelen voor interventies voor het behoud van productintegriteit. Voortbouwend op deze typologie voor interventies voor het behoud van productintegriteit, rondt hoofdstuk 2 het voorgestelde antwoord op sub-onderzoeksvraag A af met de presentatie van een typologie voor acht ontwerpbenaderingen voor het behoud van productintegriteit. Deze typologie wordt getoond in figuur S.1 en vormt het startpunt voor hoofdstuk 3.

HOOFDSTUK 3: ONTWERPEN VOOR BEHOUD VAN PRODUCTINTEGRITEIT (ENG.: *CHAPTER 3: DESIGNING FOR PRESERVING PRODUCT INTEGRITY*) beoogt een antwoord te bieden op deelonderzoeksvraag B: "Welke leidende principes en ontwerpinterventies kunnen industrieel ontwerpers gebruiken bij het ontwerpen voor lange en verlengde productlevensduren in een circulaire economie?" Het hoofdstuk neemt de typologie van ontwerpbenaderingen voor behoud van productintegriteit, gepresenteerd aan het einde van hoofdstuk 2, als uitgangspunt en tracht de abstracte ontwerpbenaderingen te ontwikkelen tot praktische en bruikbare ontwerpstrategieën voor behoud van productintegriteit. Hoofdstuk 3 onderzoekt en bespreekt de literatuur, op zoek naar ontwerpinterventies die industrieel ontwerpers kunnen selecteren en toepassen om de verschillende ontwerpbenaderingen voor behoud van productintegriteit te ondersteunen.

Figuur S.1: Een typologie van ontwerpbenaderingen voor behoud van productintegriteit in een circulaire economie.

Tevens introduceert hoofdstuk 3 het onderscheid tussen ontwerp*richtingen*, ontwerp*benaderingen*, ontwerp*principes* en ontwerp*strategieën*. De drie ontwerp*richtingen* voor behoud van productintegriteit zijn 1) het creëren van producten die een weerstand hebben tegen overbodig worden (Eng.: *resisting obsolescence*), 2) het creëren van producten die zich lenen voor het uitstellen van het moment van overbodig worden (Eng.: *postponing obsolescence*) en 3) het creëren van producten die zich lenen voor het terugdraaien van het overbodig geworden zijn (Eng.: *reversing obsolescence*)). Ontwerp*benaderingen* beschrijven op welke manier de ontwerprichtingen voor behoud van productintegriteit ingevuld kunnen worden, bijvoorbeeld door in het ontwerp van een product te streven naar fysieke duurzaamheid, naar emotionele duurzaamheid, of naar eenvoud van onderhoud en/of reparatie. Ontwerp*principes* staan voor deeloplossingsruimtes waarbinnen industrieel ontwerpers kunnen ingrijpen op de fysieke aard van het ontwerp, zoals bijv. de selectie van materialen, de wijze van (de-)montage, mate en type van modulariteit en (de wijze van) identificatie.

Het onderscheid tussen ontwerpbenaderingen en ontwerpstrategieën is noodzakelijk omdat hoofdstuk 3 vaststelt dat vrijwel alle ontwerpbenaderingen voor behoud van productintegriteit uit de typologie die in hoofdstuk 2 is ontwikkeld worden ondersteund door nagenoeg identieke reeksen van onderliggende ontwerpprincipes. Deze vaststelling leidt tot twee belangrijke inzichten. Het eerste inzicht is dat de ontwerpprincipes die door industrieel ontwerpers geselecteerd worden om een bepaalde ontwerpbenadering te ondersteunen ook van invloed zullen zijn op andere ontwerpbenaderingen. Om industrieel ontwerpers bewust te maken van het idee dat de ontwerpprincipes die zijn gekozen ter ondersteuning van een bepaalde ontwerpbenadering – vaker wel dan niet – ook van invloed zijn op andere ontwerpbenaderingen, introduceert hoofdstuk 3 het concept van een 'driedimensionale ontwerpruimte voor het behoud van productintegriteit' (Eng.: *three-dimensional design space for preserving product integrity*), zoals getoond in figuur S.2.

Door bestaande producten in deze ontwerpruimte uit te zetten op basis van een beoordeling van het relatieve belang van de drie ontwerprichtingen voor het bewaren van productintegriteit binnen de algehele ontwerpintentie van een product, kunnen industrieel ontwerpers de

Figuur S.2: Voorbeelden van producten geplot in de driedimensionale ontwerpruimte voor behoud van product integriteit. De drie dimensies worden gevormd door de drie ontwerprichtingen voor behoud van product integriteit: weerstand tegen overbodigheid, uitstellen van overbodigheid en terugdraaien van overbodigheid.

driedimensionale ontwerpruimte voor behoud van productintegriteit gebruiken als een hulpmiddel om verschillende productontwerpen te vergelijken en hun begrip te verhogen van wat het betekent te ontwerpen voor verschillende ontwerprichtingen en intenties voor behoud van de productintegriteit.

Het tweede inzicht is dat de toepassing van de ontwerpbenaderingen (en onderliggende ontwerpprincipes) sterk afhankelijk is van de bedrijfscontext, d.w.z., de specifieke bedrijfsdoelstelling(en) die met behulp van de ontwerpbenaderingen bereikt zouden moeten worden. Hoofdstuk 3 constateert dat de zakelijke context (bijvoorbeeld de bedrijfs- en productstrategie) van een product in grote mate bepaalt hoe een bepaalde ontwerpbenadering moet worden gematerialiseerd. Zo zijn bijvoorbeeld de vereisten voor, en het gewenste eindresultaat van, het ontwerp van een product dat geschikt moet zijn voor reparatie anders voor een bedrijf dat controle wil behouden en wil zorgen dat reparaties uitsluitend door gekwalificeerd onderhoudspersoneel kunnen worden uitgevoerd dan die voor een bedrijf dat wil dat reparaties zoveel mogelijk moeten kunnen worden uitgevoerd door de gebruikers van hun producten. Ontwerpprincipes zoals toegankelijkheid (Eng.: *accessibility*) moeten in elk van deze voorbeelden anders worden geïnterpreteerd door industrieel ontwerpers, afhankelijk van de specifieke bedrijfscontext (bijvoorbeeld het beperken van toegang in het eerstgenoemde, en het vergemakkelijken van toegang in het laatstgenoemde voorbeeld). Voortbouwend op dit inzicht concludeert hoofdstuk 3 dat de acht ontwerpbenaderingen alleen een praktische leidraad kunnen bieden aan industriële ontwerpers, d.w.z., alleen bruikbare ontwerpstrategieën worden, wanneer ze worden beschouwd in samenhang met de zakelijke context van het product. Om deze reden stelt het hoofdstuk voor om de bedrijfscontext een integraal onderdeel te maken van de definities van de acht ontwerpstrategieën zoals die worden gepresenteerd aan het einde van hoofdstuk 3, te weten: ontwerp voor emotionele duurzaamheid (Eng: *design for emotional durability*), ontwerp voor fysieke duurzaamheid (Eng.: *design for physical durability*), ontwerp voor onderhouden (Eng.: *design for maintenance*) ontwerp voor repareren (Eng.: *design for repair*), ontwerp voor opwaarderen (Eng.: *design for upgrading*), ontwerp voor hercontextualiseren (Eng.: *design for recontextualizing*), ontwerp voor opknappen (Eng.: *design for refurbishing*) en ontwerp voor herfabriceren (Eng.: *design for remanufacturing*).

HOOFDSTUK 4: WAARDE CREËREN EN TE GELDE MAKEN OP BASIS VAN BEHOUD VAN PRODUCTINTEGRITEIT (ENG.: *CHAPTER 4: CREATING AND CAPTURING VALUE FROM PRESERVING PRODUCT INTEGRITY)* heeft tot doel een antwoord te bieden op deelonderzoeksvraag C: "Welke businessmodeltypen kunnen bedrijven gebruiken om waarde te creëren, te leveren en te gelde te maken op basis van lange en verlengde productlevensduren in een circulaire economie?" Het hoofdstuk onderzoekt de literatuur met als doel een typologie van circulaire bedrijfsmodellen te creëren voor behoud van productintegriteit in een circulaire economie. Het hoofdstuk introduceert het concept 'circulair bedrijfsmodel voor het behoud van productintegriteit' en stelt drie criteria vast waaraan bedrijfsmodellen moeten voldoen om zich als zodanig te kwalificeren, te weten: 1) ze moeten opgebouwd zijn rond fysieke producten, 2) het behoud van product integriteit moet essentieel zijn voor hun continuïteit, omzet en winst en 3) ze moeten circulair zijn.

Hoofdstuk 4 ontwikkelt voorts een nieuwe typologie voor circulaire bedrijfsmodellen voor het behoud van productintegriteit, bestaande uit drie product-service-systeem gebaseerde typen bedrijfsmodellen: het Klassieke Lange Levensduurmodel (Eng.: *Classic Long Life model*), het Toegangsmodel (Eng.: *Access model*) en het Prestatiemodel (Eng.: *Performance model*). Daarnaast worden in het hoofdstuk drie extra typen bedrijfsmodellen geïdentificeerd die weliswaar waarde creëren en te gelde maken op basis van behoud van productintegriteit, maar die niet gekwalificeerd kunnen worden als circulaire bedrijfsmodeltypen voor behoud van productintegriteit. Strikt genomen zijn zowel het Hybride Klassieke Lange Levensduurmodel (Eng.: *Hybrid Classic Long Life model*) als het Hybride Toegangsmodel (Eng.: *Hybrid Access model*) namelijk geen circulaire bedrijfsmodeltypen voor behoud van productintegriteit, aangezien hun belangrijkste inkomstenstromen afhankelijk zijn van verbruiksgoederen met een korte levensduur in plaats van duurzame consumptiegoederen. Afhankelijk van hoe de kringlopen voor de verbruiksgoederen in specifieke gevallen echter worden opgezet, zouden ze in sommige gevallen echter wel gekwalificeerd kunnen worden als circulaire bedrijfsmodellen en als zodanig een belangrijke rol kunnen spelen in de (overgang naar) een circulaire economie. Bedrijfsmodellen van het derde type, de zogenaamde Tussenbaters (Eng.: *Gap Exploiters),* komen niet in aanmerking voor de kwalificatie van circulair bedrijfsmodel voor behoud van productintegriteit noch die van circulair bedrijfsmodel omdat ze (per definitie) geen controle hebben over het ontwerp van de producten waarvan ze het leven verlengen. Het Tussenbater model is echter wel opgenomen in het hoofdstuk omdat het een belangrijke rol kan spelen in de overgang naar een absolute circulaire economie.

DEEL TWEE

Aan de hand van gegevens en inzichten die uit de literatuur en bedrijfsinterviews en bezoeken zijn verzameld, brengt deel twee de afzonderlijke elementen van het theoretische kader uit Deel Eén samen met als einddoel het ontwikkelen van een nieuwe methodologie voor het ontwerpen van producten met een lange of verlengde levensduur in een circulaire economie.

HOOFDSTUK 5: HET MANAGEN VAN OVERBODIGHEID (ENG.: *CHAPTER 5: MANAGING OBSOLESCENCE*) heeft tot doel antwoord te geven op deelonderzoeksvraag D: "Welke leidende principes en managementstrategieën kunnen bedrijven gebruiken bij het creëren, leveren en te gelde maken van waarde op basis van lange en verlengde productlevensduren in een circulaire economie?" Het doel van hoofdstuk 5 is om leidende principes en managementstrategieën voor circulaire bedrijfsmodellen voor behoud van productintegriteit te identificeren of te ontwikkelen, aangezien deze uiteindelijk bepalend zijn voor de doelstellingen die industrieel ontwerpers middels de strategieën voor behoud van productintegriteit moet helpen te bereiken. Op basis van de huidige literatuur beschrijft hoofdstuk 5 het maximaliseren van

NL

de circulariteit van bedrijfsmodellen als het unieke extra bedrijfsdoel dat circulaire bedrijfsmodeltypes voor behoud van productintegriteit onderscheidt van bedrijfsmodeltypen voor lange en verlengde productlevensduren in een lineaire economie. Het hoofdstuk identificeert twee belangrijke barrières voor het maximaliseren van de circulariteit van een businessmodel: 1) de willekeurige fluctuaties in de stroom van overbodig geworden producten, en 2) een discrepantie tussen de acties die vereist zijn om bedrijfseconomische doelstellingen te bereiken en de acties die nodig zijn om milieudoelstellingen te bereiken. Vervolgens gaat het hoofdstuk in op de vraag hoe circulaire bedrijfsmodellen voor behoud van productintegriteit de eerste belangrijke barrière kunnen slechten, d.w.z. hoe circulaire bedrijfsmodellen voor behoud van productintegriteit hun mate van controle over de stroom van overbodig geworden producten kunnen maximaliseren. Aangezien de huidige literatuur alleen benaderingen bevat voor het beïnvloeden van de stroom van overbodig geworden producten, maar geen enkele voor het daadwerkelijk beheersen van de stroom van overbodig geworden producten, introduceert hoofdstuk 5 het concept 'managen van overbodigheid' (Eng.: *managing obsolescence*) als een nieuwe management- en ontwerpbenadering voor het ondersteunen van het creëren, leveren en te gelde maken van waarde op basis van lange en verlengde productlevensduren in een circulaire economie. Bij het ontwikkelen van het concept van het managen van overbodigheid wordt een leemte in de huidige literatuur geïdentificeerd: de huidige literatuur geeft geen inzicht in factoren - anders dan het ontwerp van het tastbare product - die een rol kunnen spelen binnen bedrijven bij het succesvol produceren en verkopen van producten met een lange levensduur en die als zodanig gebruikt zouden kunnen worden door industrieel ontwerpers (en andere zakelijke professionals) om de stroom van overbodig geworden producten te beheersen. Om een begin te maken met het opvullen van deze leemte in de literatuur en inzicht te krijgen in hoe bedrijven werken die momenteel producten met een lange levensduur produceren en op de markt brengen en welke uitdagingen zij daarbij tegenkomen, worden vijf bedrijfsinterviews en twee, meerdaagse, bedrijfsbezoeken uitgevoerd. De uitkomsten van de interviews en de bezoeken maken duidelijk dat, naast het ontwerp van het tastbare product, een groot aantal andere factoren – zoals bijvoorbeeld het type productrecht dat verhandeld wordt, de merkidentiteit, de bedrijfscultuur, contractuele afspraken, (relaties met) leveranciers, (relaties met) werknemers, (relaties) met klanten, niveau en type service, kanalen, regels en voorschriften en de interne organisatiestructuur, kortom, elementen uit vrijwel de gehele structuur van het bedrijfsmodel – de haalbaarheid en het succes van productie en marketing van producten met een lange of verlengde levensduur beïnvloeden en daarom in overweging genomen dienen te worden bij het plannen van het managen van overbodigheid.

De essentie van het managen van overbodigheid ligt in het feit dat succesvol behoud van de productintegriteit niet zozeer uitsluitend afhankelijk is van hoe goed een product blijft functioneren in de tijd (d.w.z., een tastbaar productontwerp en een ontwerptaak), maar in plaats daarvan vooral steunt op het behouden van de gepercipieerde waarde van een product in de tijd (d.w.z., een gecombineerde taak van tastbare productontwerp en -engineering en de marketingfunctie).

HOOFDSTUK 6: EEN ONTWERPMETHODOLOGIE VOOR HET MANAGEN VAN OVERBODIGHEID (ENG.: *CHAPTER 6: A DESIGN METHODOLOGY FOR MANAGING OBSOLESCENCE*), bouwt verder op het antwoord op deelonderzoeksvraag D gepresenteerd in hoofdstuk 5, en ontwikkelt een ontwerpmethodologie voor het managen van overbodigheid. Als onderdeel van dit proces biedt het hoofdstuk tevens een antwoord op deelonderzoek vraag E: "In hoeverre zijn sommige combinaties van ontwerpinterventies en typen bedrijfsmodellen waarschijnlijk meer succesvol in het creëren, leveren en te gelde maken van waarde op basis van lange en verlengde productlevensduren in een circulaire economie dan andere?"

De nieuwe ontwerpmethodologie voor het managen van overbodigheid bestaat uit vijf nieuwe ontwerpmethoden en is bedoeld om industrieel ontwerpers in staat te stellen hun productontwerpen toe te snijden op specifieke circulaire bedrijven voor behoud van productintegriteit die streven naar het maximaliseren van de circulariteit van hun bedrijfsmodel. De nieuwe ontwerpmethodologie verschilt van – en vormt een aanvulling op – bestaande ontwerpmethodologie voor het (duurzaam) ontwerpen van producten met een lange en/of verlengde levensduur omdat ze zowel rekening houdt met het ontwerp van het fysieke product als met het ontwerp van de algehele waardepropositie(s) en de bedrijfsmodellen die deze waardepropositie(s) moeten ondersteunen gedurende de gehele levensduur van het product. Naast (en gebruikmakend van) de ontwerpmethode van de driedimensionale ontwerpruimte voor behoud van de productintegriteit die al eerder in hoofdstuk 3 werd geïntroduceerd, introduceert hoofdstuk 6 vier nieuwe ontwerpmethoden ter ondersteuning van het ontwerpen voor het managen van overbodigheid: (de ontwikkeling van) een 'overbodigheidsprofiel' (Eng.: *obsolescence profile*), (de ontwikkeling van) een 'longitudinale waardepropositie' (Eng.: longitudinal value proposition), de ontwikkeling van een 'longitudinaal bedrijfsmodel' (Eng.: longitudinal business model) en het 'heuristisch raamwerk voor ontwerpen voor het managen van overbodigheid '(Eng.: heuristic framework for design for managing obsolescence). Het overbodigheidsprofiel voor een product beschrijft, voor de volledige levensduur van een product, de vooraf bepaalde reeks van tijdstippen waarop een product overbodig zal worden en de manier(en) waarop de overbodigheid van een product zal worden uitgesteld en/of teruggedraaid. Als zodanig legt het de vooraf bepaalde reeks gebruikscycli (uitgedrukt in bijvoorbeeld aantal en duur) van een product vast waarmee een onderneming met een circulair bedrijfsmodel voor behoud van productintegriteit de circulariteit van haar bedrijfsmodel kan maximaliseren voor dit product. (De circulariteit van een bedrijfsmodel is in hoofdstuk 4 van dit proefschrift gedefinieerd als de fractie van economische waarde toegevoegd aan (g) rondstoffen die in de loop van de tijd behouden wordt.) Omdat de eigenschappen van een product echter kunnen en zullen variëren tussen gebruikscycli (een opgeknapt product is bijvoorbeeld iets anders dan een gloednieuw product), zal de bijdrage van het fysieke product aan de algehele waardepropositie waarin het is ingebed waarschijnlijk dienovereenkomstig verschillen. Waar een nieuwe smartphone bijvoorbeeld kan worden aangeboden als onderdeel van een premium geprijsd serviceplan, zou een gereviseerde telefoon hoogstwaarschijnlijk een serviceplan met gereduceerde tarieven vereisen om te resulteren in een voor de klant aantrekkelijke, en voor de onderneming haalbare, waardepropositie.

De longitudinale waardepropositie beschrijft de vooraf bepaalde set waardeproposities waarin veranderingen in de eigenschappen van het tastbare product die ontstaan bij het doorlopen van het overbodigheidsprofiel worden gecompenseerd door bijvoorbeeld veranderingen in prijs en/of serviceniveau zoals vereist over de gehele levensduur van een product, d.w.z., langs het volledige overbodigheidsprofiel van het product.

Het longitudinale bedrijfsmodel beschrijft de vooraf bepaalde reeks bedrijfsmodellen die nodig is voor ondersteuning van de longitudinale waardepropositie langs het overbodigheidsprofiel, en is noodzakelijk omdat in sommige gevallen de verschillende waardeproposities verschillende bedrijfsmodellen nodig hebben om ze te ondersteunen (bijvoorbeeld verschillende kanalen of verschillende voornaamste partners). Het heuristisch raamwerk voor het ontwerpen

NL

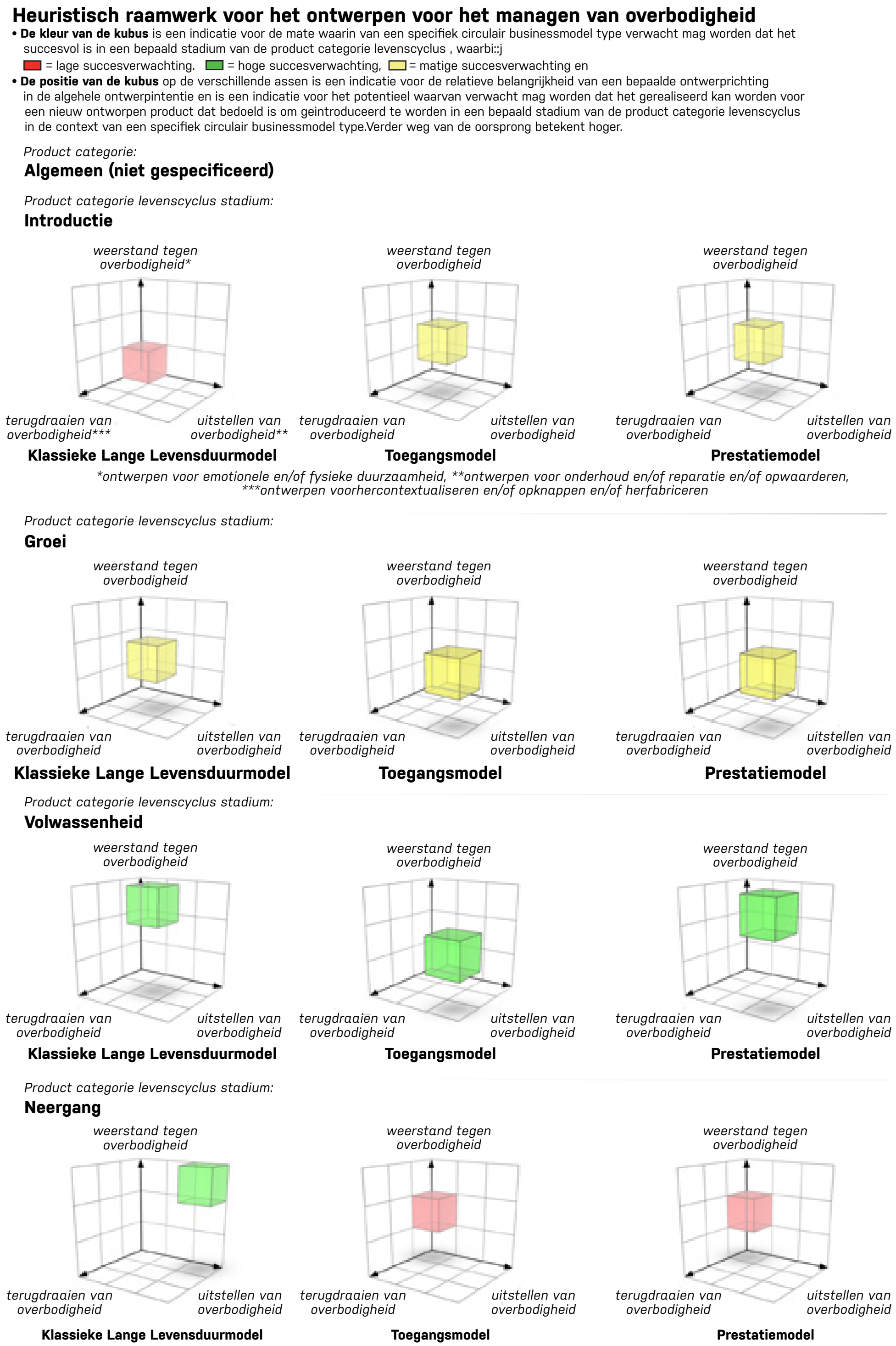


Figure S.3: Een heuristisch raamwerk voor het ontwerpen voor het managen van overbodigheid gebaseerd op de gevolgtrekkingen zoals gepresenteerd in deelsectie 6.4.2.

voor het managen van overbodigheid is bedoeld om industrieel ontwerpers te helpen bij het aangaan van de nieuwe uitdagingen waarvoor zij zich gesteld zien bij het ontwerpen voor het managen van overbodigheid in een circulaire economie (d.w.z. ontwerpen in zowel de *tijdsdimensie* als de *ruimtelijke* dimensie en het selecteren van ontwerprichtingen in combinatie met circulaire bedrijfsmodellen voor behoud van productintegriteit). Het raamwerk beoogt dit te doen door industrieel ontwerpers (en andere zakelijke professionals) een leidraad te bieden voor het selecteren van ontwerprichtingen en circulaire bedrijfsmodeltypen voor behoud van productintegriteit die ze kunnen gebruiken bij het ontwikkelen van overbodigheidsprofielen, longitudinale waardeproposities en longitudinale bedrijfsmodellen. Omdat theoretische en empirisch gevalideerde gegevens met betrekking tot welke specifieke combinaties van ontwerprichtingen en op product-service systemen gebaseerde (circulaire) bedrijfsmodeltypen succesvol zijn ontbreken in de bestaande literatuur, is het heuristische raamwerk geconstrueerd op basis van gevolgtrekkingen. Alhoewel deze gevolgtrekkingen het resultaat zijn van zorgvuldige reflectie in het licht van de secundaire gegevens en de 20-jarige branchekennis van de auteur, worden deze gevolgtrekkingen uiteindelijk gemaakt op basis van onvolledige (bijvoorbeeld omdat geen rekening gehouden is met de effecten ten gevolge van het producttype) en niet gevalideerde informatie. In hoofdstuk 6 wordt het heuristisch raamwerk, zoals getoond in figuur S.3, daarom gepresenteerd als een conceptuele propositie. Dientengevolge dient de versie van het heuristisch raamwerk zoals hier gepresenteerd als generiek te worden beschouwd en wordt erkend dat het als zodanig een beperkte voorspellende waarde heeft. Een vergelijking tussen de voorspellingen voor succesvolle combinaties van ontwerprichtingen en circulaire bedrijfsmodellen uit het heuristisch raamwerk en die combinaties zoals gevonden voor de twaalf bestaande producten levert bijvoorbeeld niet alleen een aantal perfecte en bijna perfecte overeenkomsten op, maar ook een paar verschillen. De voorspellende waarde van de versie van het heuristische raamwerk zoals gepresenteerd in hoofdstuk 6 is echter van secundair belang. Het primaire doel van het heuristisch raamwerk voor het ontwerpen voor het managen van overbodigheid zoals gepresenteerd in hoofdstuk 6 is tweeledig: ten eerste dient het om te illustreren hoe de auteur zich een methode voor het ontwerpen voor het managen van overbodigheid voorstelt. D.w.z. een ontwerpmethode die op integrale wijze zowel de verschillende mate waarin van combinaties van ontwerprichtingen en circulaire bedrijfsmodeltypen verwacht kan worden dat ze succesvol zijn vastlegt en communiceert alsook aangeeft hoe deze verschillen samenhangen met verschillende producttypen, levensfasen en circulaire bedrijfsmodeltypen met als uiteindelijk doel om een leidraad te bieden aan industrieel ontwerpers (en andere zakelijke professionals) bij het selecteren van ontwerprichtingen en circulaire bedrijfsmodeltypen bij het ontwerpen voor het managen van overbodigheid.

Ten tweede benadrukt het een geconstateerde leemte in de literatuur met betrekking tot informatie over de mate waarin bepaalde combinaties van ontwerprichtingen en circulaire bedrijfsmodellen naar verwachting succesvol zullen zijn. Als zodanig onderstreept het de noodzaak van verder onderzoek voor het geval dat de wens mocht bestaan om het concept van het managen van overbodigheid en de ontwerpmethodologie voor het managen van overbodigheid te operationaliseren als onderdeel van (de overgang naar) een absolute circulaire economie.

NL

HOOFDSTUK 7: CONCLUSIES EN AANBEVELINGEN (ENG.: *CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS*) presenteert de belangrijkste conclusies van de studie, die hieronder zijn samengevat.

In antwoord op de centrale onderzoeksvraag – "welke ontwerpmethodologie kan industrieel ontwerpers helpen bij het ontwerpen van producten die zijn afgestemd op bedrijfsmodellentypen voor het creëren, leveren en te gelde maken van waarde op basis van lange en langere productlevensduren in een circulaire economie?" – betoogt het proefschrift dat om de kans te vergroten dat productlevensverlenging in een circulaire economie succesvol zal zijn vanuit zowel een milieu als een economisch perspectief, industrieel ontwerpers niet alleen de *ruimtelijke* dimensie (materialisatie en geometrie) van producten, maar ook de *tijdsdimensie* van producten vorm moeten kunnen geven. Deze temporele dimensie houdt verband met het aantal en de duur van productgebruikscycli en de lengte van de totale levensduur van het product. Om industrieel ontwerpers in staat te stellen deze tijdsdimensie vorm te geven presenteert het proefschrift:

- een nieuwe ontwerpmethodologie: ontwerpen voor het managen van overbodigheid;
- vijf nieuwe ontwerpmethoden en twee typologieën ter ondersteuning van het managen van overbodigheid;
- inzicht in (de factoren die bepalen) hoe en wanneer deze methoden het best kunnen worden toegepast;
- inzicht in waar en in samenwerking met wie deze methoden toe te passen in het productinnovatieproces.

Eén van de belangrijkste inzichten die is opgedaan bij de ontwikkeling van de ontwerpmethodologie voor het managen van overbodigheid, is dat het managen van overbodigheid niet beschouwd dient te worden als 'confectie', maar dat om succesvol te kunnen zijn het (ontwerpen voor) het managen van overbodigheid in plaats daarvan oplossingen vereist die zorgvuldig 'op maat gemaakt' zijn en rekening houden met factoren zoals het producttype, de levenscyclusfase van het product (deel)categorie, de verschillende typen circulaire bedrijfsmodellen alsmede met culturele voorkeuren en managementoverwegingen (bijv. strategische overwegingen) over de gehele levensduur van het product. De ontwerpmethodologie voor het managen van overbodigheid zoals gepresenteerd in dit proefschrift biedt industrieel ontwerpers (conceptuele proposities voor) methoden die zijn bedoeld om hen te helpen te werken met de bovengenoemde factoren, en een betere grip te krijgen op hoe deze factoren de vereisten voor het ontwerp van het tastbare product beïnvloeden, bij het ontwikkelen van dergelijke op maat gemaakte oplossingen.

Aangezien (de ontwerpmethodologie voor) het managen van overbodigheid impliceert dat tastbare producten tezamen met overbodigheidsprofielen, longitudinale waardeproposities en longitudinale bedrijfsmodellen ontworpen moet worden in een iteratief proces, zal de rol van industrieel ontwerpers veranderen van een overwegend operationele naar een meer bedrijfsstrategische rol. Dit vereist dat industrieel ontwerpers nog nauwer moeten gaan samenwerken met professionals uit andere, nu al meer strategisch ingestelde, bedrijfsfuncties zoals bijvoorbeeld marketing dan nu al het geval is en dat zij zich vertrouwd dienen te maken met bepaalde aspecten van de theorie en terminologie van de bedrijfswetenschappen. Dit laatste lijkt in eerste instantie misschien een ontmoedigend vooruitzicht, maar zal uiteindelijk het belang van de rol en de vaardigheden van de industrieel ontwerper vergroten.

Voor onderzoekers (op het gebied van ontwerpen) biedt de ontwerpmethodiek voor het managen van overbodigheid een structuur om de resultaten van eerder en huidig onderzoek naar productlevensduren en verlenging van de productlevensduur te interpreteren, opnieuw te evalueren en/of te benutten. Ook levert het een overzicht van mogelijkheden voor toekomstig onderzoek. Het voorspellend vermogen van het heuristische raamwerk voor het ontwerpen voor het managen van overbodigheid zou bijvoorbeeld vergroot kunnen worden door het raamwerk te verfijnen en/of verschillende versies te creëren voor specifieke productcategorieën of industrieën. Ook zouden bijvoorbeeld de inzichten in de toepassing van individuele ontwerpprincipes specifiek vanuit het perspectief van een productlevensduur verdiept kunnen worden. Aangezien productlevensduurverlenging of behoud van productintegriteit slechts in beperkte mate relevant is in een lineaire economie in vergelijking met een circulaire economie, zijn er veel aspecten van de verlenging van de productlevensduur die in het verleden weliswaar zijn onderzocht, maar nooit beoordeeld zijn in het kader van het managen van overbodigheid, zoals bijvoorbeeld onderzoek naar bedrijfszekerheid, onderhoud en montage en demontage.

Hetzelfde kan worden gezegd van inzichten die zijn verkregen uit decennia van ontwerp- en marketingonderzoek. In een lineaire economie zijn veel van deze inzichten vooral gebruikt om consumenten te motiveren om snel nieuwe producten te kopen of bestaande producten snel te vervangen. Bij her-evaluatie in het kader van het managen van overbodigheid, zouden deze inzichten misschien nieuwe informatie kunnen bieden over hoe consumenten gemotiveerd kunnen worden om hun producten langer te houden. Deze informatie zou een aanvulling kunnen vormen op reeds bestaand onderzoek met betrekking tot dit onderwerp.

Voor zakelijke professionals die betrokken zijn bij de productie en marketing van fysieke en duurzame producten, betekent het managen van overbodigheid dat ze hun huidige bedrijfsmodellen moeten heroverwegen, omdat deze – waarschijnlijk – gebaseerd zijn op herhaalde productverkopen en niet zijn ontworpen om te profiteren van behoud van de productintegriteit.

De ontwerpmethodologie voor het managen van overbodigheid die gepresenteerd wordt in dit proefschrift is ontwikkeld op basis van theorie en is niet empirisch getest of gevalideerd. Als zodanig is er de noodzaak voor toekomstige validatie alvorens deze ontwerpmethodologie operationeel zou kunnen worden gemaakt. Deze taken vallen echter buiten het bestek van dit proefschrift.

REFERENTIES SAMENVATTING:

Charter M., & Tischner U. (2001). Sustainable Solutions. Developing Products and Services for the Future. Sheffield, UK: Greenleaf.

Faber, N., Jorna, R., & Van Engelen, J. O. (2005). The Sustainability of "Sustainability"—A Study into the Conceptual Foundations of the Notion of "Sustainability". *Journal of Environmental Assessment Policy and Management, 7*(01), 1-33.

Stahel, W. R. (2010). *The Performance Economy (2nd ed.)*, Hampshire, UK: Palgrave Macmillan Hampshire.

NL

PUBLICATIONS

Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology, 21*(3), 517-525 (Special Issue on the Circular Economy).

Den Hollander, M. C., Bakker, C. A. (2016). Circular Business Models for Product Lifetime Extension. *Proceedings of the EGG (Electronics Goes Green) 2016 conference.* September 7-9, 2016, Berlin. Germany.

Bakker, C. A., Den Hollander, M. C., Van Hinte, E. & Zijlstra, Y. (2015). *Products That Last – Product ontwerpen voor circulaire businessmodellen*. Delft, The Netherlands: TU Delft Library/Marcel den Hollander IDCR.

Bakker, C. A., Wang, F., Huisman, J., & Den Hollander, M. C. (2014). Products That Go Round: Exploring product life extension through design. *Journal of Cleaner Production, 69*, 10-16.

Bakker, C. A., Den Hollander, M. C., Van Hinte, E. & Zijlstra, Y. (2014). *Products That Last – Product design for circular business models.* Delft, The Netherlands: TU Delft Library/Marcel den Hollander IDCR.

Den Hollander, M. C., Bakker, C. A. (2012). A business model framework for product life extension. *Proceedings of the Sustainable Innovation 2012 17th International Conference*. 29-30 October, 2012. Bonn, Germany.

PENDING PUBLICATION

Bakker, C. A. , Den Hollander, M. C., Peck, D., & Balkenende, R. (expected 2018). Chapter 12: Circular Product Design: Addressing Critical Materials Through Design. In: Offermans, E. (Ed.), *Materials in a Resource Constrained World.*

ACKNOWLEDGEMENTS

Although at times my experience of the process of writing this dissertation strongly seemed to suggest otherwise, one does not produce a thesis out of nothing. I would therefore like to begin this section by mentioning that there is a long list of wonderful, inspiring, selfless, smart, wise, creative and courageous people that I am forever indebted and grateful to. As our paths crossed, joined and sometimes – unfortunately - separated over the years, these old and new friends, colleagues and mentors have profoundly affected my personal life and career, making it possible for me to get to the point where I am right now. Thank you, you know who you are.

In the narrower context of this thesis, I would like to start by expressing my gratitude to Conny Bakker, my promotor, for presenting me with the opportunity to become involved in the 'Products That Last' research project that really started all this for me and for subsequently helping me find my way in the academic world after 20 years of commercial design practice. Together with Han Brezet, it was Conny who made it possible for me to embark on my journey as a PhD candidate.

I also would like to thank Erik Jan Hultink, who took a big leap of faith when he agreed to become my other promotor soon after Han had announced he could no longer fulfil this role. Conny and Erik Jan, a big thank you for the guidance, support, trust, commitment and stamina that you exhibited over all these years towards this - sometimes strong-willed - PhD candidate.

I would also like to thank the (representatives from) the various companies that were involved as project partners and/or interviewees, providing me with valuable learning experiences and insights that contributed significantly to the research and would otherwise have been impossible for me to come by. The same goes for the many students that I was fortunate enough to meet and/or allowed to mentor during my research at the Delft University of Technology.

From a scientific point of view, my thesis would not have been what it is now without the constructive criticism of the members of my PhD committee. Thank you all for your willingness to be part of my committee and for inspiring and challenging me to make the most out of my research.

Yvo, thank you so much for making the book look so great, both inside and out. Ingrid and Dave, many thanks for wanting to be my paranymphs. Paul and Joël, thank you for checking on my English (any remaining linguistic abominations are mine alone).

Dear Mom, dear Dad, a million thanks for always having allowed and enabled me to follow my dreams. I'm amazed by and proud of how you are handling the things life is throwing at you right now and still manage to find energy to support me. B&B, thank you for always jumping in and for hearing me out (but not necessarily agreeing).

I would like to close by thanking my wife Marianne and son Len. Thank you for your unconditional love and unwavering support, for taking the hits, bridging the gaps, juggling the plates and most of all, for making it all worthwhile!

ABOUT THE AUTHOR

Marcel den Hollander was born on the 31st of May 1967 in The Hague. He studied Industrial Design Engineering at the Delft University of Technology and graduated (cum laude) in 1991. In 1994 he was voted one of the three best graduates over the first 25 years of the faculty of Industrial Design Engineering and awarded the prof. Schierbeek prize.

He has been working for over twenty years in industrial design for (inter)nationally renowned design studios and clients. The vast spectrum of design projects he has been involved in ranges from fast moving consumer goods, such as (food)packaging, to durable consumer goods, such as electronics, (office)furniture, and professional products, such as retail in- and exteriors, museum showcases, means of transport, industrial equipment and logistic systems. His long-standing interest in sustainable product design, combined with the changing landscape of business and industrial design has led him into the field of design research in order to explore the options for making design for sustainability an integral part of commercial industrial design practice.

From 2012 through 2015, Marcel worked as a researcher in the Design for Sustainability department at the Faculty of Industrial Design Engineering of his alma mater, becoming a PhD candidate late 2013. His research specialization is in strategic product design for circular business models.

He is co-author of the book 'Products That Last – Product design for circular business models', that is currently being used at the Faculty of Industrial Design Engineering at the Delft University of Technology in their Towards Circular Product Design course and that was adopted by the Dutch Ministry of Infrastructure and Environment to promote the circular economy and circular product design principles to small and medium sized enterprises (SMEs) in the Netherlands.

To disseminate the results of his research, Marcel has been giving guest lectures at design and business schools in the Netherlands and presented his research at a number of international conferences and consults on product design for circular business models.

This thesis argues that in order to increase the likelihood that product lifetime extension in a circular economy will be successful from both an environmental and an economic perspective, industrial designers need to be able to control not only the spatial dimension (materialization and geometry) of products, but also their temporal dimension. This temporal dimension is related to the number and duration of product use cycles and the duration of the total product lifetime. To enable industrial designers to capture this temporal dimension, the thesis presents:

- a new design methodology: design for managing obsolescence;
- five new design methods and two typologies in support of managing obsolescence;
- insight into (the factors determining) how and when to best apply these methods;
- insight into where and in collaboration with whom to apply these methods in the product innovation process.

TU Delft

9 789082 873603