NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTAMENT OF ENVIRONMENTAL SCIENCES AND ENGINEERING

DESIGN FOR CIRCULAR ECONOMY IN A STRONG SUSTAINABILITY PARADIGM

A CONTRIBUTION BASED ON CORPORATE SUSTAINABILITY MANAGEMENT, DESIGN MANAGEMENT AND SUSTAINABILITY SCIENCE

MARIA CRISTINA TOMÁS FERREIRA DE SOUSA ROCHA

Master in Sanitary Engineering

DOCTORATE IN ENVIRONMENT AND SUSTAINABILITY

NOVA University Lisbon

October, 2023

DEPARTAMENT OF ENVIRONMENTAL SCIENCES AND TECHNOLOGY

DESIGN FOR CIRCULAR ECONOMY IN A STRONG SUSTAINABILITY PARADIGM

A CONTRIBUTION BASED ON CORPORATE SUSTAINABILITY MANAGEMENT, DESIGN MANAGEMENT AND SUSTAINABILITY SCIENCE

MARIA CRISTINA TOMÁS FERREIRA DE SOUSA ROCHA

Master in Sanitary Engineering

Adviser: Maria Paula Baptista da Costa Antunes
Full Professor, NOVA University Lisbon

Co-adviser: Paulo Jorge Sintra Almeida Partidário
Principal Researcher, Directorate General for Energy and Geology

Examination Committee:

Chair: Maria Júlia Fonseca de Seixas
Full Professor, NOVA School of Science and Technology, NOVA University Lisbon

Rapporteurs: Arne Remmen
Full Professor, Aalborg University
Ana Margarida Ribeiro Dias Fernandes Gomes Ferreira
Assistant Professor with Habilitation, Beira Interior University

Adviser: Paulo Jorge Sintra Almeida Partidário
Principal Researcher, Directorate General for Energy and Geology

Members: Sofia Gago da Câmara Simões
Principal Researcher, National Laboratory of Energy and Geology
Maria Júlia Fonseca de Seixas
Full Professor, NOVA School of Science and Technology, NOVA University Lisbon
Nuno Miguel Ribeiro Videira Costa
Associate Professor, NOVA School of Science and Technology, NOVA University Lisbon

DOCTORATE IN ENVIRONMENT AND SUSTAINABILITY
NOVA University Lisbon
October, 2023

Design for Circular Economy in a Strong Sustainability Paradigm

A contribution based on corporate sustainability management, design management and sustainability

I dedicate this to my son and to my parents.

ACKNOWLEDGMENTS

To start with, I would like to express my heartfelt gratitude so my supervisors Paula Antunes and Paulo Partidário, for all the support you have given me from a scientific point of view and for your human qualities and solidarity. This combination was for sure a determinant of me being able to complete the lonesome journey that carrying out a PhD entails, especially while keeping a full-time job throughout the whole process.

I would also like to thank Arne Remmen for the support, encouragement and constructive criticism. My thanks go also to Han Brezet, for the opportunity of working in the Design for Sustainability Programme of Delft University of Technology. This was a long time ago, but the learnings from those days remain until today.

To my colleague and friend Paula Trindade, "compagnon de route" in different dimensions of life including work, here is my gratitude for our in-depth and long talks, your support and companionship. I also thank my colleagues with whom I've been working in the field of design for sustainability, Jorge Alexandre and David Camocho. It's been a pleasure and a privilege to team up with you for all these years. A special word goes to another colleague and friend, Paula Duarte: we've been together in so many projects and your kindness and amazing sense of organization are never forgotten. And my very wise and knowledgeable former colleague Rui Frazão, thanks to your friendship and great discussions about sustainability-related topics!

To all my colleagues at the Resource Economics Unit of LNEG (*Laboratório Nacional de Energia e Geologia*): I do appreciate the excellent, vibrant atmosphere and good relationship we were able to build in the past 4 years. A special word goes to our coordinator, Sofia Simões: thank you very much for your support, understanding and pragmatism.

A heartfelt word of gratitude to Mário Ramos, a PhD colleague with whom I had the privilege of working recently: you've been always supportive, encouraging and available to help. Thank you and I look forward to continuing our collaboration.

My dear friends from abroad, Kim Christiansen, Kirsten Schmidt and Willi Sieber: with you I've experienced the best possible combination of work and leisure and I'm very thankful for having your company in special moments in my life. You've been an inspiration, professionally and personally. You know you mean a lot to me.

I would like to thank all my friends, whose emotional support was fundamental for me to keep the mental strength necessary to complete this PhD. I am most grateful, many thanks, you know who you are.

Finally, my deepest appreciation to the family members whose love is a pillar in my life: my beloved son Hugo, always gentle, assertive and with a refined sense of humour, thank you for your encouragement and for being the amazing human being you are. To my dear mum (a force of nature) and sister, thank you for your love and support.

"Design, if it is to be ecologically responsible and socially responsive, must be revolutionary and radical in the truest sense. It must dedicate itself to nature's principle of least effort, in other words, maximum diversity with minimum inventory or doing the most with the least. That means consuming less, using things longer and being frugal about recycling material."

—Victor Papanek, *Design for the Real World: Human Ecology and Social Change*, 1985, pp.346–347

ABSTRACT

This thesis deals with the role of design in the contribution of businesses to the goal of achieving a sustainable development. Its importance has been recognized for decades, but it was not before the end of the last century that academia, some front-running companies, consultants and standardization bodies started to develop schemes on how to systematically apply environmentally conscious design and, later on, design for sustainability (DfS) in the design and development of products, services and systems. Nevertheless, the systematic and widespread uptake of this important sustainability strategy at micro-level did not have the desired expression and it was observed that despite the extensive literature on the subject, there is still a lack of a common understanding of DfS is and how to operationalize it.

Building on corporate sustainability management and design management theories, an analytical framework to analyse DfS models was developed, consisting of nine elements at strategic, tactical and operational levels, and applied through an extensive literature review. This allowed us to conclude that the analytical framework (and its underlying theories) were adequate to analyse and compare the studied models and to identify priority areas for further development: establishing a sustainability vision to which companies are encouraged to contribute through their products and services/business models, integration of DfS in the business strategy at the highest decision-making level, cocreation with stakeholders, the adoption of design strategies and criteria that address the economic and social components of sustainability and the sustainability assessment of the new solutions.

However, it was not before the emergence of circular economy (CE) in the political agenda (the first circular economy action plan of the European Union was released in 2015) that ecodesign/DfS finally received a remarkable attention. In this respect, there was a wealth of publications on circular design strategies, to which this thesis also contributes by proposing strategies and criteria that fill gaps in previous proposals, namely addressing social criteria in design.

Nevertheless, CE is subject to criticism regarding its actual contribution to sustainability. This fact, combined with the realization that sustainability schemes adopted by companies are mostly aligned with weak sustainability, made us question the potential of design for CE to address the enormous challenges our societies face; therefore, we aimed at the development of a model of design for CE in a strong sustainability paradigm assisted by adequate guiding principles. Through an iterative consultation process using the Delphi method, a conceptual model was developed, building both on the learnings of the analysis of the DfS models and on its theoretical foundation. Furthermore, the Delphi research has led to a new definition of design for circular economy in a strong sustainability paradigm and contributed to clarify the relationship between circular economy and strong sustainability. The thesis closes with promising research directions to further develop the model and its application to different need areas and respective value chains.

Keywords: design for sustainability, circular economy, design for circular economy, strong sustainability, implementation model, design management, corporate sustainability management.

Resumo

Esta tese trata do papel do design na contribuição das empresas para o objetivo de alcançar um desenvolvimento sustentável. A sua importância tem sido reconhecida há décadas, mas foi só no final do século passado que o meio académico, algumas empresas líderes, consultores e organismos de normalização começaram a desenvolver modelos para a aplicação sistemática de um design ambientalmente consciente e, posteriormente, design para a sustentabilidade (DpS) na conceção e desenvolvimento de produtos, serviços e sistemas. No entanto, a adoção sistemática e generalizada desta importante estratégia de sustentabilidade a nível micro não teve a expressão desejada e observou-se que, apesar da extensa literatura sobre o assunto, ainda falta um entendimento comum sobre o DpS e como operacionalizá-lo.

Com base nas teorias de gestão de sustentabilidade empresarial e gestão de design, foi desenvolvido e aplicado um quadro analítico com nove elementos aos níveis estratégico, tático e operacional, para analisar modelos de DpS através de uma extensa revisão da literatura. Isto permitiu-nos concluir que o quadro analítico (e as teorias subjacentes) foram adequados para analisar e comparar os modelos estudados e identificar áreas prioritárias para um maior desenvolvimento: estabelecer uma visão de sustentabilidade para a qual as empresas são encorajadas a contribuir através dos seus produtos e serviços/modelos de negócio, integração do DpS na estratégia de negócio ao mais alto nível de decisão, cocriação com *stakeholders*, adoção de estratégias e critérios de design que abordem as componentes económicas e sociais da sustentabilidade e avaliação da sustentabilidade das novas soluções.

Mas não foi antes do surgimento da economia circular (EC) na agenda política (o primeiro plano de ação de economia circular da União Europeia foi lançado em 2015) que o ecodesign finalmente recebeu uma atenção notável. A este respeito, proliferaram publicações sobre estratégias de design circular, para as quais esta tese também contribui, ao propor estratégias e critérios que respondem a lacunas comuns das propostas anteriores, nomeadamente abordar critérios sociais no design.

No entanto, a EC é alvo de críticas quanto à sua real contribuição para a sustentabilidade. Este facto, combinado com a constatação de que os esquemas de sustentabilidade adotados pelas empresas estão maioritariamente alinhados com a sustentabilidade fraca, fez-nos questionar o potencial do design para a EC para enfrentar os enormes desafios que as nossas sociedades enfrentam; assim, foi definido o objetivo de desenvolver um modelo de design para a EC num paradigma de sustentabilidade forte, apoiado por princípios orientadores adequados. Através de um processo iterativo de consulta utilizando o método Delphi, foi desenvolvido um modelo conceptual, baseado tanto nas aprendizagens da análise dos modelos de DpS, como na sua fundamentação teórica. Para além disso, a investigação realizada através do método Delphi deu origem a uma nova definição de design para a economia circular num paradigma de sustentabilidade forte e contribuiu para clarificar a relação entre economia circular e sustentabilidade forte. A tese termina com perspetivas de investigação promissoras para uma maior especificação do modelo e a sua aplicação a diferentes áreas de necessidade e respetivas cadeias de valor.

Palavras-chave: design para a sustentabilidade, economia circular, design para a economia circular, sustentabilidade forte, modelo de implementação, gestão do design, gestão da sustentabilidade empresarial.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms

BM	Business model
CE	Circular economy
DfS	Design for sustainability
IQR	Inter-quartile range
PSS	Product-service system
RQ	Research question
SQ	Sub-question
SDG	Sustainable Development Goals

1

INTRODUCTION

1.1 Context and motivation

Shifting to sustainable consumption and production patterns, particularly in high income countries, has been advocated over more than 50 years (considering as landmarks e.g. the 1972 United Nations Conference on Human Environment and the publication of 'Limits to growth' (Meadows et al., 1972)), since the ecological crisis – overexploitation of resources, pollution and disruption of the Earth's natural processes – is directly linked to which, how and how much goods are produced and consumed (Bengtsson et al., 2018). In 2015 the United Nations launched the 2030 Agenda for Sustainable Development with its core 17 sustainable development goals, one being precisely responsible consumption and production (UN General Assembly, 2015).

Businesses have been urged to engage in sustainable consumption and production and one approach to deal with this challenge that has gained momentum since the 1990's is ecodesign (Brezet & van Hemel, 1997; U. Tischner et al., 2000), i.e., the integration of environmental considerations in design and development of products with the aim to reduce adverse environmental impacts throughout their life cycle (International Electrotechnical Commission, 2019).

The concept of ecodesign has evolved from the focus on how to improve or redesign a single product, from environmental and economic points of view and within the realm of established technologies, to questioning the function the product is providing and developing new product-service combinations that comply with such function; or even going further and questioning and changing the whole system (the combination of artefacts, infrastructures, economic models, socio-cultural values and institutional frameworks), designated as design for sustainability (DfS) (A.Idil Gaziulusoy & Brezet, 2015). This type of more radical innovations, covering not only environmental concerns, but also social ones, is deemed as necessary to achieve sustainability. Another relatively recent concept that concurs to the same purpose is circular design or design for circular economy. Its definition is not consensual, but one can say that it seeks the development of products and business models that ideally eliminate waste and pollution by functioning in closed-loop systems and whose value is kept at the highest level, for as long as possible (Ellen MacArthur Foundation, 2015).

Kate Raworth showed in her book 'The Doughnut economics : seven ways to think like a 21st-century economist' (Raworth, 2017), in a very impactful way, that global social foundation still falls short of life's essentials such as food, education and housing; at the same time, the ecological ceiling defined by the planetary boundaries (Rockström et al., 2009; Steffen et al., 2015) has been overshot in six out of the nine boundaries (Richardson et al., 2023).

This is a clear indication that decades of work in environmental and sustainability management in companies and their value chains has not produced the expected results at global level, since various indicators have been worsening over the years (the above-mentioned planetary boundaries, as well as the Earth overshoot day (*Earth Overshoot Day*, n.d.), the global circularity rate (Circle Economy, 2023) and the Human Development Index, which globally presents a slight declining trend in the past few years (*Human Development Reports*, n.d.)).

It is estimated that 80% of the environmental impact of a product throughout its life cycle is determined at the design stage (Nasr et al., 2018, p. 9) and therefore ecodesign and, moreover, DfS and design for circular economy are seen as a particularly powerful tools for companies to adopt a truly sustainable behaviour, in contrast with other sustainability oriented business practices that focus on determined stages of the life cycle of products or on specific topics and overlook the whole life cycle and the potential of more radical innovations. The questions are, then: (1) is it the case that the uptake of ecodesign/DfS/design for circular economy has not been expressive enough to drive the required transformation on the production-consumption system and (2) even if they were widely disseminated and implemented, would the sustainability landscape be drastically different, for the better?

This thesis focuses on both questions. Firstly, by contributing to characterize DfS models or frameworks that have been proposed by academia, under the assumption that the uptake of DfS is more likely to be successful if informed by corporate sustainability management and design management theories. Secondly, by addressing the question of *how to guide companies in the circular design and development of new products, product-service systems and business models so that they actually contribute to sustainable development?*

There is empirical evidence that even in countries where circular design has had a remarkable expression, the overall circularity rate has not increased. This is the case of The Netherlands, a leading country in circular economy (Totaro, 2023), where the CIRCO – *Creating business through circular design* Programme has trained over 2000 companies in circular design with a rate of implementation of new, circular designs of 70% (van Os, 2023, oral communication) and the total quantity of natural resources used in the country has remained unchanged since 2010 (Totaro, 2023).

Realizing that, although there is an increase in the adoption of sustainability practices by companies, paradoxically the environmental quality worsens, several authors note the need to align methods and models of corporate sustainability management with strong sustainability (Bjørn & Røpke, 2018; Demastus & Landrum, 2023; Landrum, 2018; Landrum & Ohsowski, 2018; Nikolaou et al., 2019), which is not currently happening (Demastus & Landrum, 2023). The same call applies to design for sustainability and business model innovation; (Brozovic, 2020; Ayse Idil Gaziulusoy, 2010).

Trying to respond to the findings above, this thesis aims at developing a model of design for circular economy in a strong sustainability paradigm. One can argue that the solution to the sustainability challenges goes way beyond the agency of companies; it is complex, multidimensional and asks for rethinking the global economic system towards a sustainable society; but even in such scenario companies and their value networks would need to be equipped to function and thrive in such new paradigm. This thesis aims to be a modest contribution to such purpose.

1.2 Research questions

The overarching research question of this thesis is:

RQ1: What should a model that supports companies in the systematic adoption of design for circular economy in a strong sustainability paradigm look like?

To answer this question, the departure point was the analysis of design for sustainability (DfS) models published in the literature in the light of corporate management and design theories. The related research questions (RQ) and sub-questions (SQ) are formulated as follows:

RQ 1.1: How do DfS models published in the literature perform in view of corporate sustainability management and design management theories?

SQ 1.1.a: *What would an analytical framework based on those theories look like?*

SQ 1.1.b: *To what extent are the DfS models in accordance with the analytical framework?*

The increasing attention that has been devoted to circular economy in academic, political and business arenas (Murray et al., 2017; Stahel, 2016), as well as its potential to tackle environmental sustainability (Ellen MacArthur Foundation, 2015; Sauvé et al., 2016) has determined the inclusion of design for circular economy in this research. An extensive academic and practical work has been devoted to the development of circular design strategies (Bocken et al., 2016; den Hollander et al., 2017; Moreno et al., 2016), and the present work contributes to such efforts by adding new elements more aligned with DfS, as formulated in the following research question:

RQ 1.2: Which circular design strategies and related criteria should be adopted by companies that:

- *Address the social dimension of sustainability;*
- *Envisage not only product, but also product-service system design;*
- *Encompass materials and energy sustainability alongside traditional circularity strategies such as slowing and closing resource loops?*

As elaborated in chapter 5, the links between circular economy and sustainability remain a subject of debate and a "circular solution" is not necessarily more sustainable (Schroeder, 2018) and for organizations and business to make substantial contributions to sustainable development, their organizational methods and tools (including those related to the products, services and business models they put on the market) should be in line with strong sustainability (Demastus & Landrum, 2023; Landrum, 2018). Following this rationale, the research questions below were addressed:

RQ 1.3: How can design for a CE in a strong sustainability paradigm be defined?

RQ 1.4: How do CE and strong sustainability relate to each other?

SQ 1.4.a: *Which are the features of CE and strong sustainability that are aligned?*

SQ 1.4.b: *Which are the features of CE and strong sustainability that are conflicting?*

RQ 1.5: What is the added value of a model that supports companies in the design for a CE in a strong sustainability paradigm?

RQ 1.6: Which are the most important elements of a model of design for a CE in a strong sustainability paradigm?

1.3 Research contribution

In line with the objective and the research questions, the contributions of this thesis can be summarized as follows:

- Advancing the knowledge on design for sustainability (DfS) in the light of corporate sustainability management and design management theories, through a broad literature review presented in chapter 3, which resulted in the development of an analytical framework to study existing DfS models and unveiling their strengths and weaknesses, with the aim of promoting DfS and its adoption in practice;
- Contributing to the development of design for circular economy by proposing design strategies and criteria aligned with an understanding of circular economy in the framework of sustainable development;
- Further advancing the concept and practice of design for circular economy and its relationship with sustainability, which resulted in a new definition, an implementation model and guiding principles of design for circular economy in a strong sustainability paradigm.

2

RESEARCH DESIGN

2.1 Overarching theory

This research combines corporate sustainability management, design management and sustainability science; this combination of disciplines to produce new knowledge is a characteristic of transdisciplinary research (Darian-Smith & Mccarty, 2016), which has become an established part of the activities in society that deal with sustainability issues (Lorenz, 2022), since sustainability studies require critical, holistic and integrative thinking.

Corporate sustainability management is concerned with the contribution of companies to sustainability and encompasses approaches such as corporate environmental management, corporate social responsibility, sustainability reporting and sustainable innovations such as sustainable product and service design, among others (Baumgartner & Rauter, 2017). It combines classical management and sustainability and requires the integration of environmental and social issues in management as a prerequisite to creating societal value (Baumgartner & Rauter, 2017; Pazienza et al., 2022). A theory of (corporate) sustainability management "has the potential advantage over other management theories in more comprehensively reflecting the biophysical-based reality of human individuals, organizations, and societies and their integration with human cultures and economies" (Starik & Kanashiro, 2013, p. 13) and needs to address both short term and long term effects of management decisions on the company itself, the value network, the society and natural environment. Pazienza et al. (2022) defined corporate sustainability as "the new business paradigm that requires attention to Environmental, Social and Economic dimensions to be able to provide for current and future generations" (p, 17).

Outside academia there have been several contributions to corporate sustainability management, namely in the world of standardization: (i) the ISO standards on environmental management that constitute the whole 14000 series (ISO, n.d.-b, n.d.-a) and include environmental management systems, environmental performance evaluation, life cycle thinking and ecodesign, sustainable resource use, evaluating strategic and monetary consequences of environmental management, etc. and (ii) the ISO 26000 standard on social responsibility (ISO, 2010), among others. The ISO work is a multi-stakeholder and global effort to produce standards that contribute to terms and definitions, methods and practices that are adopted by companies, thus having a theoretical and practical added value to corporate sustainability.

Design management focuses on the principles and practices of managing the design process. According to the Design Management Institute, design management seeks to link design, innovation, technology, management and customers to provide competitive advantage across the economic, socio/cultural and environmental factors in businesses. Simply put, design management is the business side of design (Design Management Institute, n.d.). Designers support companies in managing complexity and applying design-thinking systems theory, addressing globalization and innovation needs and becoming more socially responsible organizations (Borja de Mozota, 2008). In recent years, a new focus at the intersection between design and sustainability science research has emerged, which looks at design as a way of bringing sustainability at the core of business decisions, at strategic level (Baldassarre et al., 2019).

Within sustainability science, it is also relevant for the present research to reflect in two models of sustainability: weak sustainability vs. strong sustainability. To understand this distinction, one needs to address the concept of natural capital, i.e. not man-made, in contrast to manufactured capital and human capital (labour) (Costanza & Daly, 1992). The 'weak sustainability' school proposes that development is sustainable if the sum of all capitals per capita is maintained or increased over time (Ekins et al., 2003), which means that capitals are interchangeable and the reduction of natural capital is acceptable if it is compensated by the increase in other forms of capital. Criticism to the weak sustainability model includes (Ayse Idil Gaziulusoy, 2010):

– The consideration that it is unrealistic to assume that substitution between capitals is unlimited or money can be the universal substitute for everything (Gowdy, 2005);

– For many types of natural assets, technical substitutes do not exist (Sartorius, 2006);
– The future that society will derive from capital cannot be predicted with certainty (Figge, 2005). Therefore, the weak sustainability model contradicts the requirement of not compromising the ability of future generations to meet their needs (Ayse Idil Gaziulusoy, 2010), which is part of the definition of sustainable development (WCED, 1987).

The strong sustainability model argues that natural capital to some extent can be substituted by manmade types of capital, as long as "critical natural capital" is maintained (Elkis et al., 2003, as quoted by Bjørn & Røpke, 2018). Figure 2-1 illustrates the two models of sustainability.

In figure 2-1 (left hand side), sustainable development is at the confluence between the environmental, social and economic dimension; as Moir & Carter (2012) note, this representation ignores the intrinsic, immutable relationships between each of the dimensions (Giddings et al., 2002), facilitates the perception that the substitution of physical and human capital for natural capital can occur indefinitely (Neumayer, 1999) and furthermore, areas where there is no overlap can be incorrectly perceived as being unrelated to sustainability (Lozano, 2008). The image on the right of figure 2-1 suggests a nested model with a hierarchical structure in which the economy is a subset of society and human activities are dependent on and impact upon the natural environment (Giddings et al., 2002; Moir & Carter, 2012).

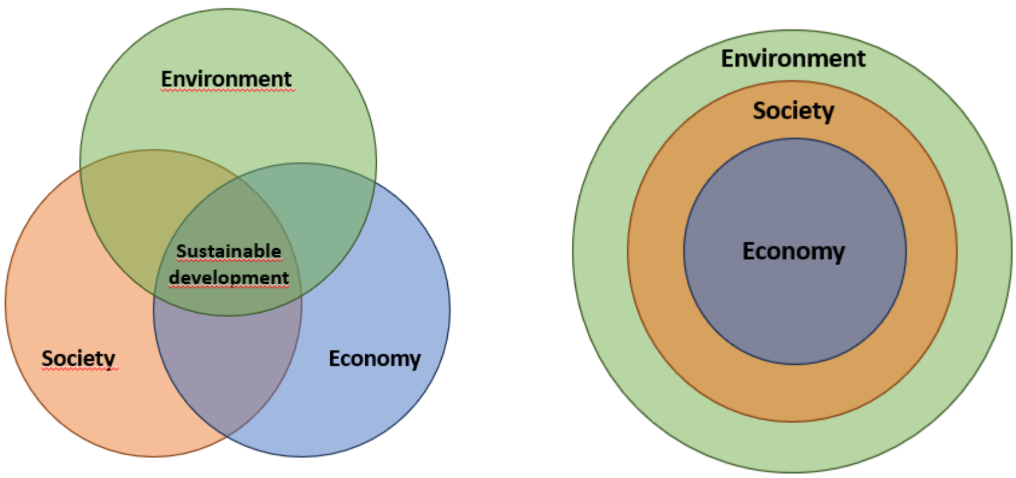


Figure 2-1: Sustainable development according to the weak sustainability model (left) and strong sustainability model (right)

Source: (Giddings et al., 2002)

The implications of these two sustainability schools at the micro level are developed in chapter 5, based on Nancy Landrum's unified model of sustainability stages (Landrum, 2018), providing insight on the adoption of the strong sustainability paradigm to answer the call to link the circular design to strong sustainability in corporate sustainability management

Figure 2-2 represents schematically the zone of intersection of the different theoretical foundations of this thesis and demonstrates its transdisciplinary character.

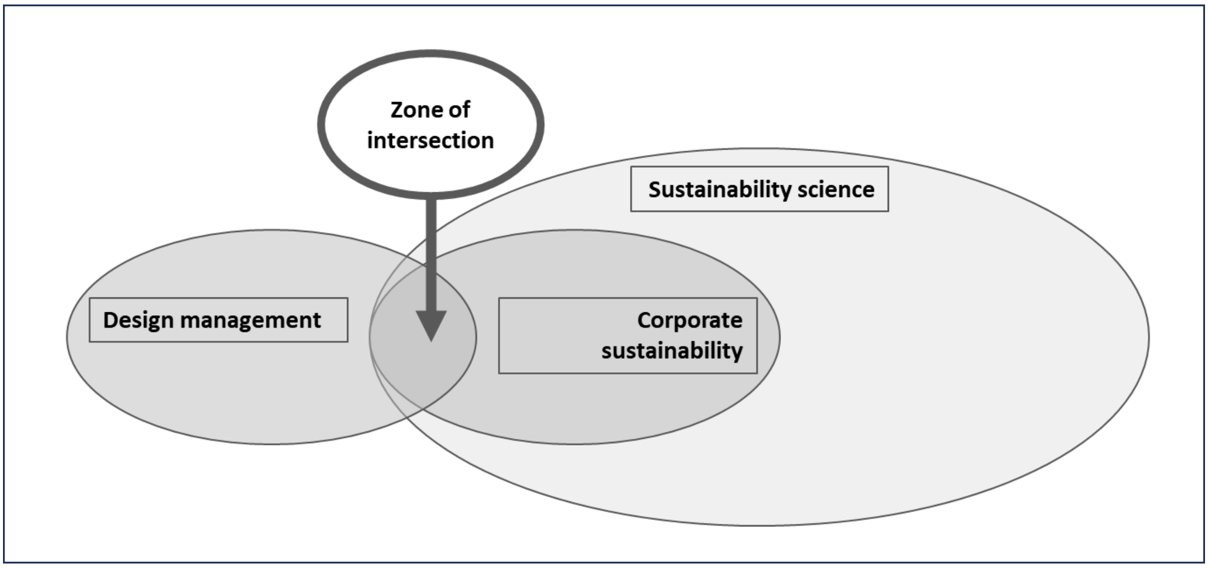


Figure 2-2: Theoretical foundations of this thesis, in the zone of intersection between different disciplines.

Source: Own elaboration

2.2 Methods

Literature review and desk research

A literature review summarizes and evaluates a series of writings on a particular topic (Knopf, 2006) in a systematic, explicit and reproducible way (Fink, 2014). Desk research is a way of organizing and summarizing information and it overlaps with literature review (Byrne, 2017).

Since this thesis is founded on existing publications from academic and grey literature, both methods have been used in chapters 3 to 6 but was particularly important for chapter 3. In this case, the literature review was done in two steps:

- Firstly, to build an analytical framework to analyse DfS models published in the literature. Using analytical frameworks offers several opportunities for the organization of research (Coral & Bokelmann, 2017);
- Secondly, to collect the published DfS models, using the following journal databases: Science Direct (http://www.sciencedirect.com), Scopus (www.scopus.com), Business Source Complete and Academic Search Complete (www.ebsco.com).

The identification of examples of circular design strategies that corresponds to the annex of chapter 4 was equally performed through desk research and exchange of information with fellow colleagues that were partners in the KATCH_e project[1], within which the chapter 4 material was produced.

Online survey using the Delphi method

According to Grime & Wright (2016), the Delphi method is particularly adequate when the subject under research can benefit from collective, subjective judgments and when group dynamics are not suitable for reasons such as time differences, distances and personality conflicts. It allows a group of experts to deal with complex problems (Linstone & Turoff, 2002) through sequential rounds of questionnaires towards the collective building of informed conclusions (Brown, 1968; de Jesus et al., 2019; Grime & Wright, 2016). It was considered a sound method to apply in chapter 5, aiming at answering to RQ's 1.3-1.6, despite the limitations that are described in the chapter.

Statistical data treatment

The results of the qualitative answers obtained through the application of the Delphi method were subject to statistical treatment with the aim of ascertaining and reaching consensus. The following assessment methods were used:

- Percentage of agreement within two categories on a five-point Likert scale (de Jesus et al., 2019).
- Mean item ranking, share (%) of experts placing an item in the top half of their list, and Kendall's W (Moslem et al., 2019).

[1]*KATCH_e project – Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability in Higher Education (project nº 575793-EPP-1-2016-1-PT-EPPKA2-KA)*

– Measures to quantify the amount of variation of dispersion: median, the IQR and the standard deviation (de Jesus et al., 2019).

2.3 Structure of the thesis

This document is organized in six chapters. Chapters 1 and 2 introduce the problem and the research context. Chapters 3 to 5 are the central ones and correspond to two individual articles and a book chapter. They can be read as stand-alone documents as they address specific questions around the contribution of design to sustainability and related implementation models. Conclusions and perspectives for further research are presented in chapter 6.

Figure 2-3 shows the relationship between the main chapters and figure 2-4 presents the overall structure of the thesis: chapters, research questions and objectives and methods. This is followed by a brief description of each chapter.

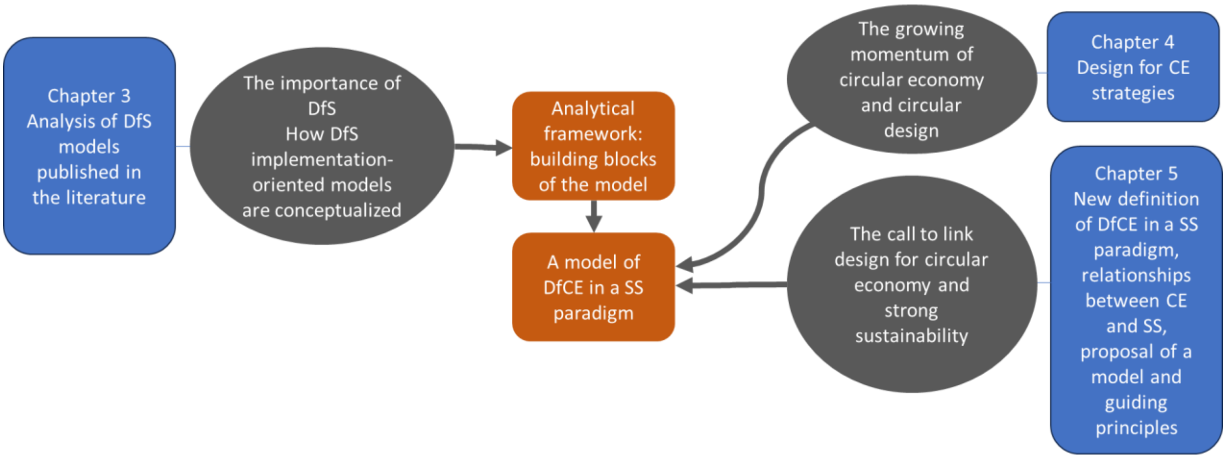


Figure 2-3: Central chapters of the thesis (in blue), the trends and problems they address (in grey) and the outcome (in orange)

Chapters			Research questions	Methods	Publications
1	Introduction				
2	Research design	RQ 1 (overarching)	All		
3	Design for sustainability models: a multiperspective review		RQ 1.1 (SQ 1.1.a and SQ 1.1.b)	Sistematic literature review	Paper 1 (published)
4	Circular design strategies		RQ 1.2	Desk research	Book chapter (published)
5	Design for circular economy in a strong sustainability paradigm		RQ 1.3 – RQ 1.6 (SQ 1.4.a and SQ 1.4.b)	Desk research Delphi: survey	Paper 2 (submitted)
6	Conclusions and recommendations		All		

Caption:
RQ: Research question
SQ: Sub-question

Figure 2-4: Structure of the thesis: chapters, related research questions, methods and publications

Chapter 1 introduces the subject of this research by presenting the context and motivation, the research questions and the research contribution.

Chapter 2 presents the research design: the overarching theory, showing the transdisciplinary character of this work and the main theoretical foundations it builds upon, the methods used (a combination of systematic literature review, desk research and a survey using Delphi, an interactive forecasting method) and the author's contribution to the different chapters.

Chapter 3 consists of a systematic literature review that resulted in (i) an analytical framework to study published design for sustainability (DfS) models based on the specified theories and (ii) the analysis itself, of 10 models published between 2000 and 2019. The main take aways of this chapter are the applicability of the theoretical background, the confirmation of the analytical framework as an adequate representation of the studied models and the identification of gaps for further study in the quest of supporting companies in the adoption of design for sustainability.

Chapter 4 takes a more practical stand by proposing design for circular economy strategies and criteria to be applied in the design and development of products and product-service systems that overcome some gaps identified in the literature. They are illustrated by examples already available in industry and constitute an intermediary step in the framing of circular economy and circular design in the context of sustainable development. This endeavour is further developed in chapter 5, where a discussion on the differences between weak and strong sustainability are presented and a contribution is given through the conceptual development of circular design as well as to its practice within a framework of strong sustainability. In this chapter, we aimed at overcoming recognized limitations in the current predominant CE and circular design discourses and answered RQ's 1.3-1.6.

Chapter 6 elaborates on conclusions and recommendations for future research.

2.4 Authors' contribution

This research was conducted by Cristina Rocha as the main author, under the supervision of Paula Antunes and Paulo Partidário as supervisor and co-supervisor, respectively. Overall, Cristina was the leading author of all chapters in this thesis. She conceptualised the ideas, developed the methodology, conducted the investigation, executed surveys, drove the formal analyses, curated the data and wrote the articles (original draft, review and editing). Paula Antunes supervised, gave feedback, reviewed and edited the research. Paulo Partidário co-supervised, gave feedback, reviewed and edited the research.

David Camocho and Jorge Alexandre contributed to chapter 4. They have read and agreed to the published version of the chapter they were involved in. Ana Afonso, Elena Mulet, João Sampaio and Laura Ruiz-Pastor provided minor inputs to the text.

The outcomes of this research are disseminated in one international conference, one peer-reviewed academic article, one book chapter, one online course and in several non-academic events involving hundreds of public and private organizations committed with circular economy and design for sustainability.

3

DESIGN FOR SUSTAINABILITY MODELS: A MULTIPERSPECTIVE REVIEW[2]

Abstract

Several authors have identified limitations in the uptake of design for sustainability (DfS) in companies and value chains. In spite of the extensive literature on the subject, researchers and practitioners still do not share a common overview on the subject, which hinders operationalization efforts. This paper proposes that DfS adoption is more likely to be successful if informed by corporate sustainability management and design management theories. Therefore, an analytical framework has been developed and applied to systematically analyse ten published design for sustainability models, which were identified through an extensive literature review. The analytical framework is composed of nine building blocks, or elements, organized in three levels: strategic, tactical and operational. To facilitate a more detailed and objective analysis of the selected models against each element, 22 questions have been

---

[2] *Published as a peer-reviewed article:*
Rocha, C. S., Antunes, P., & Partidário, P. (2019). Design for sustainability models: A multiperspective review. In Journal of Cleaner Production (Vol. 234, pp. 1428–1445). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.06.108

Previously presented at an international conference:
Rocha, C. S., Antunes, P., & Partidário, P. (2019). Design for sustainability models: A multiperspective review. 3rd LeNS World Distributed Conference, organised as part of the LeNSin, the International Learning Network of networks on Sustainability project (2015-2019). Oral presentation, Milan session, 3rd-5th of April 2019. https://lensconference3.org/index.php/general#italy-session

established. The findings show that while some authors have focused on abstract models that support companies in establishing a vision and concepts for (more) sustainable products and services, others offer more instrumental approaches to guide the different phases of design. On the level of the building blocks, there is a considerable alignment of the models with the analytical framework; the detailed mechanisms and processes for implementation, however, vary a lot. Overall, difficulties related to developing a sustainability vision that guides the design for sustainability process, co-creating with stakeholders and harmonizing environmental, social and economic criteria were identified. The social dimension of design for sustainability is still poorly established and tackled in a multi-level, non-systemized way. The paper concludes with promising research directions focusing on design for sustainability.

Keywords: Design for sustainability, design management DfS models, corporate sustainability management, social responsibility.

3.1 Introduction

The role of designers in contributing to the sustainable development agenda has been acknowledged for many years. Victor Papanek inspired the agenda of social design saying that designers and creative professionals have a responsibility and are able to cause real change in the world through good design. Already in the 1970's he wrote about his ideas for ecologically sound design and designs to serve the poor, the disabled, the elderly and other minority social groups (Papanek, 1971).

However, the sustainability-oriented design only emerged late in the 20th century when strategies, methods and tools appeared, related to ecodesign or design for environment. Although some authors pointed out the need for moving from environmental-oriented product redesign to more radical innovations, addressing not only environmental (and economic) but also social concerns (see for instance van Weenen, 1995), it was not before the 2000's that one could observe a significant effort in the development of concepts, models, tools and methods aiming at supporting industries and design professionals to include sustainability concerns in the product, service and(or) business development (see e.g. Joore and Brezet, 2015).

There are several models, tools and methods published in the literature for sustainable product and service design, including environmental, economic and social criteria, but several authors recognize limitations in their implementation and in the generation of more sustainable solutions (Ameta, 2009; Ceschin and Gaziulusoy, 2016; Maxwell et al., 2003; Tischner, 2008; Watkins, 2014). Furthermore, the diversity of approaches to design for sustainability (DfS) makes it difficult for researchers, practitioners and trainers to gain a common overview on the subject, particularly when integrated in the broader sustainability management in companies. Moreover, DfS research has to a great extent excluded the importance of project management (Ali et al., 2016) and this may be an obstacle to the practical implementation of DfS, ultimately hampering the prospects of a wide uptake by industry and professionals involved in design. Consequently, the related potential sustainability gains remain relatively unexploited.

Several concepts and approaches appeared with the purpose of providing a basis to manage sustainability at companies' level, grounded on business management, stakeholders' theory, environmental sciences and social sciences, namely: environmental, quality, health and safety and energy management systems; stakeholders' engagement; social responsibility; and environmental and sustainability communication. The linkage between these initiatives and design has not been clear and often simply missing. While these various principles, strategies, approaches and tools may be complementary and conceptually related, it has been difficult to integrate them into product and design contexts (Küçüksayraç, 2015; Richardson et al., 2005; Salari and Bhuiyan, 2016).

In this paper, we addressed these concerns by analysing the characteristics of existing DfS models. We propose that corporate sustainability management and design management provide the basis for a systemic and systematic implementation of design for sustainability and thus take this assumption as a framework for the analysis.

Other authors published review papers that analyse DfS and ecodesign models and tools (Ahmad et al., 2018; Blizzard et al., 2012; Brones and Monteiro de Carvalho, 2015; Gaziulusoy, 2015; Salari and Bhuiyan, 2016; Vasantha et al., 2012) but nevertheless research specifically on DfS is scarce and shows a variety of perspectives and goals. The only study that takes a similar approach to the one used in this paper has been performed by Brones and Monteiro de Carvalho (2015), but it concerns ecodesign and not DfS. Thus, a systematic review of existing DfS models or frameworks to understand their alignment with corporate sustainability management and design management theory is expected to contribute to advance DfS knowledge and its wider adoption.

After the presentation of the design for sustainability concept and its evolution in section 3.2, the method used for the literature review is explained in section 3.3. Sections 3.3.2.1 and 3.3.2.2 provide the theoretical background on sustainability management and design management, resulting in an analytical framework developed for this research (section 3.3.2.3). Results and discussion are presented in section 3.4 and section 3.5 closes the paper with the conclusions, limitations and perspectives for future work.

3.2 Understanding design for sustainability (DfS)

The discussion around the concept of design for sustainability starts by defining "design". According to the Design Research Portal, "design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life cycles" (DRP, 2017).

The integration of environmental considerations in design with the objective of reducing environmental impacts of products along their life cycle, known as ecodesign, life cycle design or design for the environment, has been subject of research (e.g. van Hemel, 1998; Klostermann and Tukker, 1998; Stevels, 2009; Myrdal, 2010), and tools and methods development (Brezet and van Hemel, 1997; Behrendt et al., 1997; Tischner et al., 2000) since the late 1990's. Ecodesign is part of the wider concept of product life cycle management, which complements potential environmental gains achieved through design decisions, once a product is launched and stays in the market, sometimes for a long period (Vila et al., 2015). Key characteristics of ecodesign include life cycle thinking (i.e. considering the environmental aspects and associated impacts in all life cycle stages), and early integration (i.e., addressing environmental considerations at the earliest possible stage of product development (Thrane and Eagan, 2007), when there is more room for introducing radical changes to the product concept and optimize outcomes. Another key characteristic of the ecodesign work in the late 1990's is that of integrating the concept of functional thinking where the main focus is not the product to be designed but the function(s) it delivers (Ceschin et al., 2010; Vezzoli and Ceschin, 2011).

This evolution from the focus on products to the focus on solutions is illustrated in the well-known four levels of sustainable design innovation proposed by Brezet (1997):

- Level 1: Product improvement, focused on reducing single environmental impacts and involving partial changes and improvements to products already existing in the market.
- Level 2: Product redesign, in which the product is fully redeveloped with an environmental life-cycle perspective.
- Level 3: Functions innovation, which is no longer confined to the existing product concept; in this case, the way the function is fulfilled is changed. The general shift from products to services (development of product-service systems) belongs to this category.
- Level 4: System innovation, where the entire socio-technological system (the product, the production chain, infrastructure, economic models, social cultural values and institutions) is replaced by a new system.

By broadening the scope to more social-driven approaches, the ecodesign concept evolved and design for sustainability (DfS) emerged. DfS includes more radical innovations in the product, questioning its function and thus influencing the existing patterns of consumption, which are expected to give a far bigger contribution to sustainable development (Rocha and Brezet, 1999; Tukker and Tischner, 2006; Tischner, 2008). Therefore, product design initiatives having a great diversity of purposes showed a progressive involvement of the respective supply chains, and therein of their change agents (Van Der Heijden et al., 2010; van der Heijden and Cramer, 2017).

Spangenberg et al. (2010) note that "some definitions of ecodesign, derived to distinguish it from mainstream design, go beyond incremental gains. However, these definitions were made in the absence of DfS as an additional category" (p. 1490). These authors systemize the difference between ecodesign and DfS as presented in Fig. 3-1, highlighting that DfS broadens the horizon and challenges established practices. It increases the level of complexity and risk of solutions, which is inevitable in the case more radical innovations when compared to incremental improvements (Spangenberg et al., 2010).

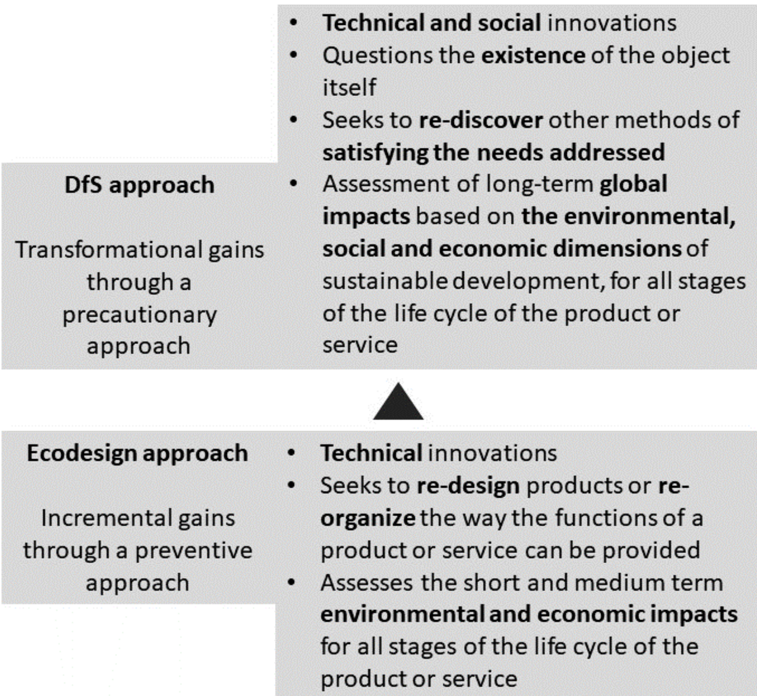


Figure 3-1: From ecodesign to DfS (adapted from Spangenberg et al., 2010).

In the Wuppertal Institute Design guide (Liedtke et al., 2013, p.15), the definition of DfS is "… all about establishing or maintaining the individual's quality of life without limiting the potential well-being of other people or future generations …", and with that purpose "… includes the promotion of a sustainable use of environmental space …" and "… needs to provide social-technical solutions that didactically foster appropriate transition processes". Organizations interact with each other, in the supply chain and more broadly in network-oriented views. Those organizational innovations enabled stakeholders' involvement across and beyond supply chains, to get key players to understand new issues and embrace new visions, and to have the change agents gaining the support of the main chain actors (Evans et al., 2007; Partidário and Vergragt, 2002; Quarshie et al., 2016; Rossi et al., 2000).

In their work on design for sustainability, several authors such as Richardson et al. (2005), Spangenberg et al. (2010), Tischner (2008) and Vezzoli and Manzini (2008) adopt a wide understanding of design, in terms of the design scope and even the level of change attained (e.g. from designing products to designing life- styles, see Richardson et al. (2005), p.15), where designers are facilitators of innovations e product, technological, organizational and societal. They are engaged in solutions that are not limited to physical products, but rather to product-service combinations that fulfil the users' needs e also called product-service systems (PSS). PSS have deserved the attention of sustainability experts since the early 2000's as a possible strategy to dematerialization by providing utility to consumers through the use of services rather than products (Mont, 2002).

As Vezzoli and Ceschin (2011, p.23) summarize it: "In synthesis, over the last few decades, the role of design has increased in relevance and recognition, enlarging its field of action from the selection of materials and energies, to the design of the product life cycle, to the design of eco-efficient system innovation, to the inclusion of socio-ethical aspects".

Building upon the several contributions to understanding the concept of DfS, in this paper the following definition is adopted:

DfS is a holistic design approach that enables to integrate and assess the sustainability dimensions in different stages of the product or product-service development process towards the required scale of incremental and/or radical innovations.

3.3 Method

3.3.1 Literature review

In this section the method used to perform the literature review (a systematic, explicit and reproducible method (Fink, 2014)) of DfS models is presented.

The following journal databases were used for the literature search: Science Direct (http://www.sciencedirect.com), Scopus (www.scopus.com), Business Source Complete and Academic Search Complete (www.ebsco.com). Table 3-1 summarizes the search terms, expanders and limiters. The Boolean operator AND was used to limit the results related to design for sustainability and its variations to models, frameworks or methods, which are the object of this research; besides, only relevant academic disciplines were selected. The time frame from year 2000 onwards was chosen due to the evolution of the concept development of DfS, as presented in section 3.2.

Comparatively, "Sustainable design" AND (model or framework or method)" had a very high number of results. In order to have a workable amount, in this particular case another filter was applied, limiting the subject to "sustainable design" and excluding subjects such as "sustainable building design and construction", "sustainability", etc. Thus, in this case the results that follow are limited to 444 through the application of the filter.

Table 3-1: Overview of the literature search.

Search terms (Boolean phrase)	Expanders	Limiters	Academic disciplines selected for the review
• "Design for sustainability" AND (model or framework or method) • "Sustainable design" AND (model or framework or method) • "Sustainable product design" AND (model or framework or method) • "Sustainable product development" AND (model or framework or method)	• Apply equivalent subjects • Apply related words	• Peer review • Time frame: 01/01/2000-30/03/2019 • Type of source: academic journals	• Applied Sciences • Business and Management • Engineering • Science • Visual Arts

The results per Boolean phrase (excluding exact duplicates) are presented in Table 3-2.

Table 3-2: Results of the literature search per Boolean phrase.

Boolean phrase	Number of results (excluding exact duplicates)
"Design for sustainability" AND (model or framework or method)	251
"Sustainable design" AND (model or framework or method)	1068
"Sustainable design" AND (model or framework or method) with the subject filter "sustainable design"	444

Table 3-2 (continued): Results of the literature search per Boolean phrase.

Boolean phrase	Number of results (excluding exact duplicates)
"Sustainable product design" AND (model or framework or method)	45
"Sustainable product development" AND (model or framework or method)	187

Fig. 3-2 presents the distribution of the results per publication, in which the Journal of Cleaner Production clearly outstands.

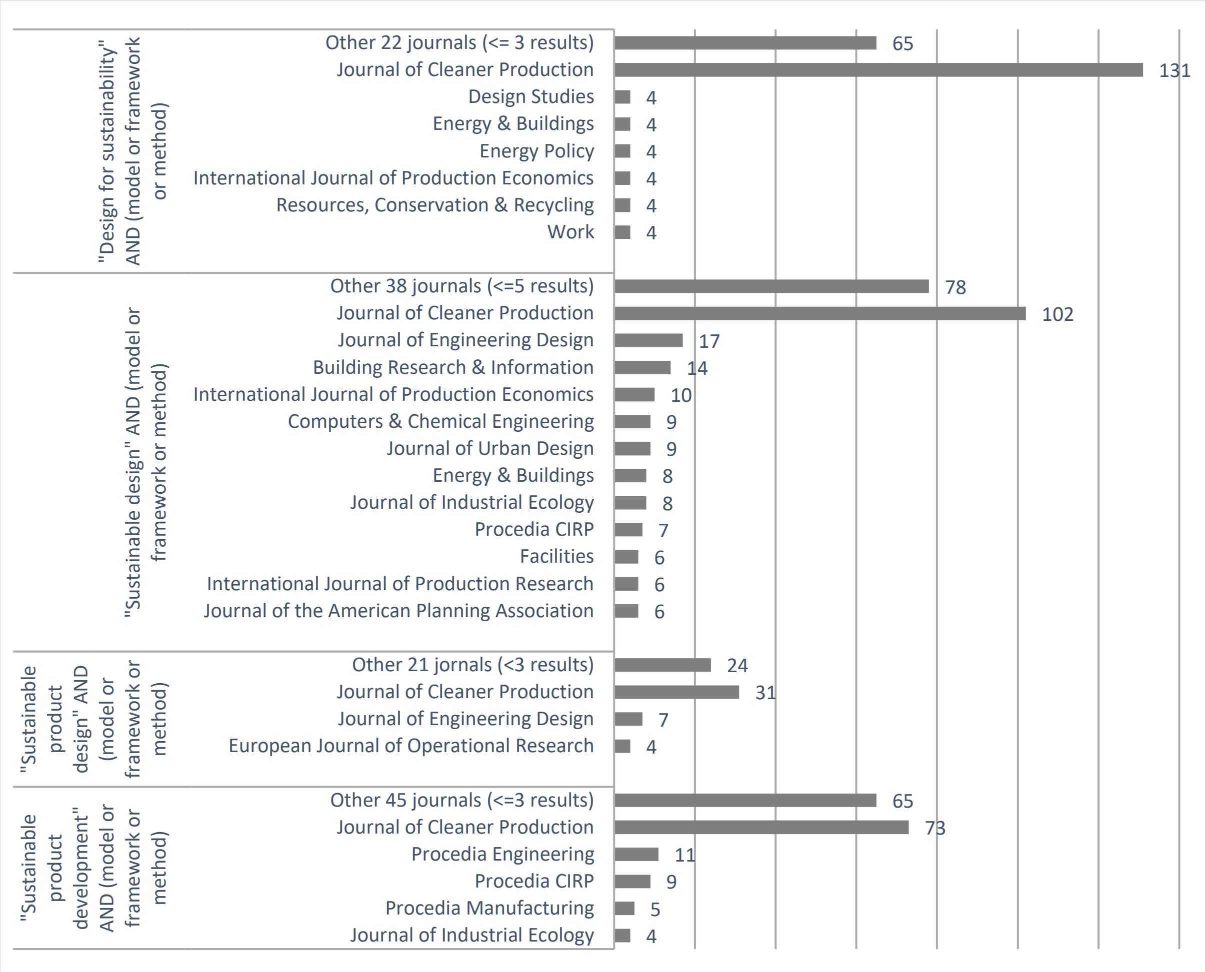


Figure 3-2: Number of publications related to the Boolean phrases applied in the review, per journal.

The abstracts and the full papers, when necessary, of all publications shown in Table 3-2 (in the case of "sustainable design", applying the subject filter) were analysed. It was necessary to focus the research, to be coherent with the understanding of DfS presented in section

3.2 and to obtain a workable number of models, given the exhaustive character of the analysis. Therefore, the selection criteria were the following:

- Only papers covering at least the environmental and social dimensions were included, as many publications are limited to environmental considerations in design (i.e., ecodesign) despite of the word "sustainable" and its variants occurring in the keywords; a few of those are related to social design and overrule the environmental dimension; in both cases they were discarded.
- Publications just addressing specific design strategies, e.g., design for X (recycling, remanufacturing, etc.) i.e., lacking the necessary holistic approach pursued in this research were therefore excluded.
- Procedural models (best practices to guide designers in practical situations) and abstract models (offering theories and conceptual insights into design and development) (Wynn and Clarkson, 2017) were included in the review. On the other hand, several models that focus solely on the assessment part of DfS were found; they were not considered, because the approach followed in this paper is action-oriented.
- A considerable amount of literature addressed case studies on DfS that were not bringing novelty to the models or to the frameworks behind and was also excluded.

Adding to that, the references' lists of the most relevant publications found in this process were also examined using the same criteria, thus enriching the review and allowing for the inclusion of other publication types, e.g. relevant books and grey literature.

3.3.2 Development of a framework to analyse DfS models

3.3.2.1 Corporate sustainability management

Since its seminal definition in the Brundtland Report (WCED, 1987), the concept of sustainable development has given rise to several macro-level principles (e.g., United Nations Declaration on Human Rights, The Natural Step System Conditions (Nattrass and Altomare, 1999), the United Nations Millennium Development Goals (United Nations, 2017a), the United Nations Sustainable Development Goals (United Nations, 2017b)), strategies (e.g., cleaner production, eco-efficiency, design for sustainability), and issue- and industry-specific criteria and guidelines (e.g., certification schemes for environmental management systems or sustain- ability reporting, and a variety of labels, such as ecolabels, fair trade labels, etc.).

The role of business in supporting sustainable development has been acknowledged for a long time and several authors argued for the possibilities of linking responsibility towards the society and with environment with improved business opportunities (Schmidheiny, 1992; von Weizsacker et al., 1998). But it is a very complex task for an organization to align its strategic planning, decision making and operational and tactical processes with sustainable development principles and goals. This challenge was addressed initially by Robèrt et al. (2002) through the development of the 'System Level' model, a hierarchical "map" for comprehensive planning in any complex system, utilizing a successful outcome in the future complying with four basic principles of environmental and social sustainability (Robèrt, 2000, p. 245):

"In the sustainable society, nature's functions and diversity are not subject to systematically increasing …

i. Concentrations of substances extracted from the Earth's crust.
ii. Concentrations of substances produced by society.
iii. Physical impoverishment by over-harvesting or other forms of ecosystem manipulation. And, in that society …
iv. Resources are used fairly and efficiently in order to meet basic human needs worldwide."

Following an extensive literature review of strategic management, corporate social responsibility, and corporate sustainability, Baumgartner (2014) developed a conceptual framework for corporate sustainability management, whose foundations are based on the work by Robèrt et al. (2002); Baumgartner combines three organizational basic variables, i.e. organizational structure, formal management instruments, and organizational culture and proposes a way of integrating sustainability aspects on different management levels: normative management, strategic management and operational management; furthermore, his model encompasses the identification of contextual factors to identify the relevance of sustainable development and the significant sustainability aspects. This framework is supported by instruments related to performance measurement, assessment and evaluation, operational management or strategic management and is organized as follows (Baumgartner, 2014):

1) Normative positioning - aiming at ensuring and enhancing legitimation of corporate activities by stakeholders and the society: who are we and who do we want to be?

- Corporate vision and policy

– Corporate governance
– Organizational culture

2) Determine contextual factors

– General business environment factors: political, technological, economic, societal, environmental
– Sector-specific factors (Porter's 5 Forces)
– Stakeholders factors: demands from internal and external stakeholders

3) Strategic planning - what are our strategic goals?

– Passive or active strategic orientation; if active:
– Long term goals: backcasting/forecasting/the four sustainability principles
– Strategy type, specific goals and activities

4) Operational management e efficiency

– Implementation of normative and strategic goals within all corporate activities

Another robust contribution is the instrumental approach offered by the ISO 26000 - Social responsibility standard (ISO, 2010), which urges organizations to adopt a transparent and ethical behaviour that:

– Contributes to sustainable development, including health and welfare of society;
– Takes into account the expectations of stakeholders;
– Is in compliance with applicable law and consistent with international norms of behaviour; and
– Is integrated throughout the organization and practiced in its relationships (i.e., the organization's activities within its sphere of influence).

The key characteristic of social responsibility is the willingness of an organization to incorporate social and environmental considerations in its decision-making and be accountable for the impacts of its decisions and activities on society and the environment[3]. The principles, practices and core subjects described in the standard form the basis for an organization's practical implementation of social responsibility and its contribution to sustainable development.

---

[3] Corporate social responsibility is used sometimes as synonym to corporate sustainability (Baumgartner, 2014). In this paper, social responsibility, corporate social responsibility and companies' sustainability managing are used indistinctly.

Social responsibility applies to the daily operations of an organization and to its strategic decisions regarding new activities, relations, products services and business models. ISO 26000 proposes that organizations' most likely economic, environmental and social impacts are covered by seven core subjects (each of them detailed in several issues):

- Organizational governance;
- Human rights;
- Labour practices;
- The environment;
- Fair operating practices;
- Consumer issues;
- Community involvement and development.

The ISO 26000 standard calls on organizations to understand how their decisions and activities impact on the society and the environment in relation to all seven core subjects, also considering the stakeholders needs and expectations.

Unlike the previous models, the one proposed by ISO 26000 was not a result of academic research, but rather developed within a multistakeholder platform, finalised after a 6-years development process based on international consensus among some 400 experts from over 90 countries (ISO, 2010). Despite the different paths followed, it is possible to find similitudes in the 'System Level Model' (Robèrt et al., 2002), Baumgartner's (2014) conceptual framework for corporate sustainability management and the ISO 26000 standard:

- All emphasize the need for organizations to understand their role in society and the biosphere in order to set an overall vision for action;
- While the 'System Level' model and the framework for corporate sustainability management follow the four basic sustainability principles (Robèrt, 2000), ISO 26000 operationalizes sustainable development challenges through the seven core subjects and related issues (ISO, 2010). In this case, the deployment of social sustainability is more developed;
- Both in the ISO standard and in Baumgartner's framework, dealing with the complexity posed by sustainability is (at least partly) tackled through stakeholders' involvement and legitimation. The 'System Level' model uses backcasting from a desired state as a way of planning in complex systems. Therefore, while all indicate

the need of measuring and monitoring the results, in the case of the System Level Model, success implies not violating the sustainability principles, whereas in ISO 26000 monitoring ongoing performance on the activities related to core subjects and relevant issues gains from stakeholders' feedback, while mechanisms for enhancing credibility of reports and claims are foreseen;

- In all cases, operational methods, tools and indicators for performance assessment against predefined criteria are explicitly mentioned, as well as the need of integration throughout the organization, at the different levels and functions.

3.3.2.2 Design management

Design management theory is deemed fundamental in order to take into account sustainability issues in the design and development process, although current design management approaches do not necessarily include sustainability aspects in theory and in practice (Koklacova and Valdemara, 2016).

Coined in the United Kingdom by The Royal Society of Arts in 1965 (Best, 2006) the concept of design management is still evolving (Erichsen and Christensen, 2013) with roots in marketing, sociology, psychology and engineering (Vazquez and Bruce, 2002).

Peter Gorb defined it as "the effective deployment by line managers of the design resources available to a company in order to help the company achieve its objectives." (Gorb, 1990). This definition suggests that the subject is directly concerned with the organizational place of design (Best, 2015) but as Borja de Mozota (2008) notes, the context of design management has become wider due to a paradigm shift within the design profession, from an activity-based to a knowledge-based profession. This challenges designers to support companies in managing complexity and applying design-thinking systems theory, addressing globalization and innovation needs and becoming more socially responsible organizations, where "designer input can go beyond advanced design projects to invent the process for change" (Borja de Mozota, 2008, p. 36).

Design management has not a standard model to be applied by every organization, and companies work with design management at many levels from a project or function-based level to a fully integrated level where design management is a part of the organizational culture (Kootstra, 2009). Recent design management approaches are very dependent on the strategies of the companies they are developed for and integrated into (Koklacova and Valdemara, 2016). The concept of design management includes its role as an "integrator of stakeholders"

(Koklacova and Valdemara, 2016, p. 104), while recognizing their potentially competing goals as put by Lalaounis (2017) who, based on recent marketing thinking, emphasize the role of consumers and other stakeholders at the core of product/service development.

Design has a role to play at three levels in an organization: strategic, tactical and operational. According to Best (2015), at the strategic level, design must connect to the overall policies, missions and agendas; the tactical level concerns the teams, processes and systems of specific business units or functions; at operational level, design manifests itself in the tangible products, services or experiences, and corresponds to the micro-level design management that concerns the tasks relevant to the completion of individual projects and how they are organized (Staples, 2008; Antunes, 2012).

3.3.2.3 An analytical framework for DfS models

In view of the theoretical background presented in sections 3.2, 3.3.2.1 and 3.3.2.2, an analytical framework for DfS models has been established, distinguishing the strategic, tactical and operational design activities. Table 3-3 specifies the relationship between the elements of the framework and their theoretical foundations and Fig. 3-3 provides a graphic representation of the framework.

There is one element in the analytical framework that does not derive from the literature on design management and sustainability management: the aimed innovation scale (see Fig. 3-3). The reason to introduce it is the willingness to understand whether or not models which aim at higher and more complex innovation levels (according to Brezet (1997)) have a different behaviour regarding the other elements of the framework.

Table 3-3: Building the analytical framework for DfS models based on design management and sustainability management literature.

Source: Own elaboration.

Analytical framework for DfS models			
Levels	**Elements**	**Relationship with design management literature**	**Relationship with corporate sustainability management literature**
Strategic	Establishment of a sustainability vision	- Tackling globalization, innovation and social responsibility challenges (Borja de Mozota, 2008).	Normative positioning, aiming at ensuring and enhancing legitimation of corporate activities and the society (Baumgartner, 2014); Planning at the level of the overarching system (the society and the ecosphere) in which the organization operates; definition of goals within the principles for social and environmental sustainability (Robèrt et al., 2002); Commitment to contribute to sustainable development, which requires an understanding of societal expectations, including international norms of behaviour (ISO, 2010).
	Integration in the business strategy	- Overall policies, missions and agendas design must connect with (Best, 2015).	Strategic planning: what are the companies' strategic goals? (Baumgartner, 2014); Social responsibility is integrated throughout the organization and practiced in its relationships (the standard specifies this at strategic and tactical levels) (ISO, 2010).
	Stakeholder involvement	- Need to identify and involve stakeholders in the design process (Best, 2015); Design as an integrator of stakeholders (Koklakova and Valdemara, 2016); - Stakeholders as co-creators of value and central to the product and service development (Lalaounis, 2017).	Ensuring and enhancing legitimation of corporate activities by stakeholders (Baumgartner, 2014); Consideration of needs and expectations of stakeholders as a core element of an organization's social responsibility (ISO, 2010).

Table 3-3 (continued): Building the analytical framework for DfS models based on design management and sustainability management literature.

Analytical framework for DfS models			
Levels	**Elements**	**Relationship with design management literature**	**Relationship with corporate sustainability management literature**
Tactical	Social, environmental and economic criteria	-	Four principles of environmental and social sustainability, related to resources consumption, pollution, damages to eco-systems and fair and efficient use of resources to meet basic human needs (Robèrt, 2000); Seven core subjects, all to be considered: organizational governance, human rights, labour practices, the environment, fair operating practices, consumer issues, community involvement and development (ISO, 2010).
	Sustainability assessment	-	Concrete actions of companies need to be examined from a complete sustainability perspective (Robèrt et al, 2002); Processes and procedures to assess the impact of the organizations' decisions and activities on the seven core subjects (ISO, 2010).
	Integration in management systems and practices	- In a fully integrated level, design management is part of the organization's culture (Koostra, 2009); - Close relationship between design management and companies' strategies (Koklacova and Valdemara, 2006).	Implementation of sustainability normative and strategic goals within all corporate activities (Baumgartner, 2014); Social responsibility is integrated throughout the organization and practiced in its relationships (the standard specifies this at strategic and tactical levels) (ISO, 2010); Linking day-to-day monitoring to strategic reviews regarding social responsibility overall objectives (e.g. through the use of indicators), (ISO 2010).

Table 3-3 (continued): Building the analytical framework for DfS models based on design management and sustainability management literature.

Analytical framework for DfS models			
Levels	**Elements**	**Relationship with design management literature**	**Relationship with corporate sustainability management literature**
	Involvement of different internal functions	- Teams, processes and systems of specific business units or functions that are engaged in design (Best, 2015); - Multidisciplinary and knowledge-based orientation of the design profession (Borja de Mozota, 2008).	- Implementation of sustainability normative and strategic goals within all corporate activities (Baumgartner, 2014); - Integration of social responsibility in organizational functions (ISO, 2010).
Operational	Organization of the design and development process	- The way the product development process is implemented (Antunes, 2012); - How the tasks to complete individual design projects are performed and organized (Staples, 2008).	- Corporate sustainability management requires the adaptation of management processes (Baumgartner, 2014); - Processes need to be revised to make sure that they take into account social responsibility (ISO, 2010).

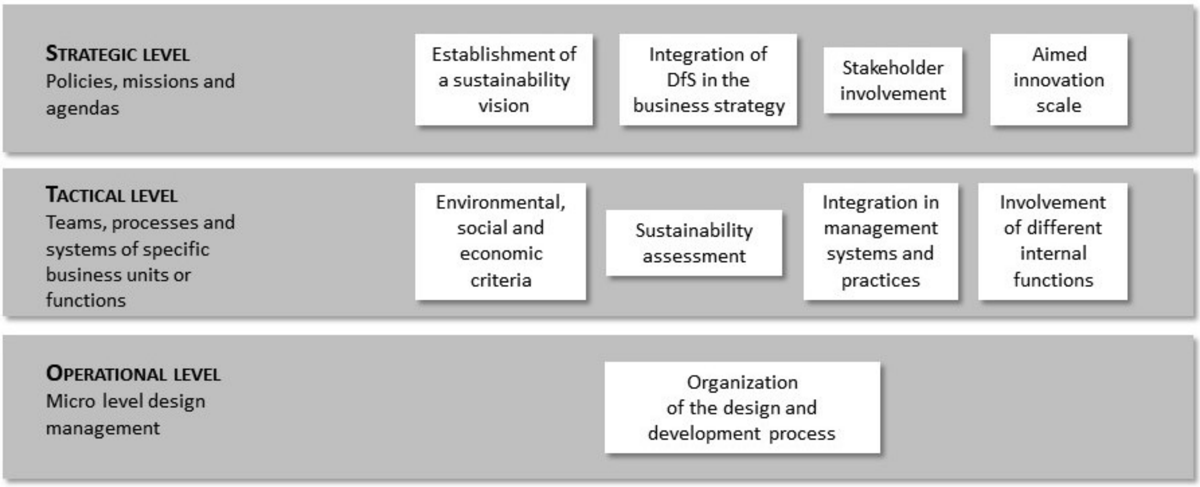


Figure 3-3: Analytical framework for the review of DfS models.

Source: Own elaboration.

In order to get a deeper understanding of the way the studied models address each element (box) of the framework, a number of questions has been developed and were used in the analysis.

DfS at strategic level

- Establishment of a sustainability vision:
    - Does the model or framework include guidance on how to establish a sustainability vision that directs the company's DfS activities and projects?
    - Does such guidance propose specific sustainability principles that should inform DfS? Which ones?
- Integration of DfS in the business strategy:
    - Is DfS added to the existing business strategy?
    - Is DfS challenging the existing business strategy leading to new business models, new partnerships, new markets, etc.?
- Stakeholder involvement:
    - Does the model include specific mechanisms to involve stakeholders in decision-making?
    - Does it provide guidance on priority stakeholders?
    - Does it provide guidance on co-creation with stakeholders, specifically with the actors in the value chain?
- Aimed innovation scale:
    - Positioning the analysed DfS models according to the four levels of innovation described in section 3.2 (Brezet, 1997), where the potential for sustainability increases from level one to level four.
    - Is the model meant to support more than one levels of innovation or is it focused on one specific level?

DfS at tactical level

- Environmental, social and economic criteria:
    - Which environmental, social and economic criteria for DfS are included in the model?
    - Is there a balance in way the model details the environmental, social and economic criteria?
    - How do models deal with trade-offs between criteria?
    - Are the environmental, social and economic criteria formulated as design principles or strategies to guide the design process?

- Sustainability assessment:
  - Which sustainability assessment methods and tools are indicated?
  - Do they cover the environmental, social and economic dimensions?
  - Do they take the life cycle into account?
  - Are those methods qualitative or quantitative?
- Integration in management systems and practices:
  - Does the model indicate specific management systems and practices where DfS should be integrated in the company?
  - Does the model provide guidance on the integration process or how the overall business management and DfS inform one another?
- Involvement of different internal functions:
  - Which organizational functions are explicitly related to DfS, according to the model?

DfS at operational level

- Organization of the design and development process:
  - How is the DfS process organized (stepwise approach, other)?
  - Does the model advocate reviewing or adapting the design and development process in order to address sustainability considerations?

Given that the analysed models vary in the sense that some are mainly conceptual, whereas others have a more procedural nature, such variety needs to be accommodated in the analysis. In the first step, the evaluation focuses simply the presence or absence of each of the elements of the framework (Fig. 3-3), with the exception of the 'aimed innovation scale' element; here in particular, there is a predefined ranking, from level one to level four (i.e. from the lowest to the highest intervention and sustainability potentials); the ranking was performed according to the description of the models by their author(s), which was quite explicit to this respect.

The detailed questions within each of the framework's elements enable a deeper understanding of the state of the art in DfS and insights on where the most important strengths and weaknesses lie. The focus then is to gain knowledge both on the which an on the how the analytical framework's elements are tackled by the analysed models, to the extent they provide detailed explanations.

3.4 Results

The literature review resulted in the identification of ten relevant models, presented in Table 3-4.

Table 3-4: Brief description of the DfS models analysed in this paper (by chronological order).

Source: Own elaboration.

Date	Author(s)	Designation	Short description
2003	Maxwell and van der Vorst	Method for sustainable product and/or service development in industry (**SPSD**)	Designed to provide a framework for implementing SPSD throughout the complete lifecycle of a product and/or service and the associated supply chain. The aim is to identify, assess and implement the options for optimising sustainability in product and/or service development. Two cases from the electronics industry are presented. (Maxwell & van der Vorst, 2003).
2004	Manzini et al.	Solution-Oriented Partnership Methodology Framework (**SOP**)	Structured, interconnected reference framework to facilitate the planning and implementation of partner-based solutions, outlining the form of the partnership, the context-of-use and the required solution architecture. It underlies the process by which different social players converge towards highly context-based, advanced industrial solutions (Manzini, Collina, et al., 2004). Applied to food delivery solutions (Manzini, Jégou, et al., 2004).
2007	Waage	Roadmap for integration of sustainability issues in product design (**ROADMAP**)	Four-phase process for integrating systems and sustainability perspectives into product design, manufacturing and delivery decision, building on previous frameworks stemming from industrial ecology, human and labour rights and corporate social responsibility. Based on the overlay of product design and sustainability processes in a company and premised on the argument that sustainability efforts require evaluating decisions in terms of consistency with broad, systems-based principles (Waage, 2007).

Table 3-4 (continued): Brief description of the DfS models analysed in this paper (by chronological order).

Date	Author(s)	Designation	Short description
2007 2008	Byggeth et al. Ny et al.	Method for sustainable product development (MSPD) + Templates for SPD (**MSPD+TEMPLATES**)	Method for sustainable product development based on backcasting from basic sustainability principles, which includes a modular system of guiding questions, throughout a concurrent engineering product development process (Byggeth et al., 2007). The templates were developed as a complement to the MSPD, to facilitate achieving an overview of the major sustainability challenges and opportunities of a product category in the early development phases (Ny et al., 2008). Given such complementarity, the MSPD and the templates are analysed together. The templates were applied to televisions at the Matsushita Electric Group (Ny et al., 2008).
2007 2008	Byggeth et al. Ny et al.	Method for sustainable product development (MSPD) + Templates for SPD (**MSPD+TEMPLATES**)	Method for sustainable product development based on backcasting from basic sustainability principles, which includes a modular system of guiding questions, throughout a concurrent engineering product development process (Byggeth et al., 2007). The templates were developed as a complement to the MSPD, to facilitate achieving an overview of the major sustainability challenges and opportunities of a product category in the early development phases (Ny et al., 2008). Given such complementarity, the MSPD and the templates are analysed together. The templates were applied to televisions at the Matsushita Electric Group (Ny et al., 2008).
2009	Crul and Diehl	Design for Sustainability: Redesign **(D4S REDESIGN)**	Structured, stepwise approach for redesign for sustainability. D4S Redesign aims at redesigning an existing product made by a company, including its primary function and any associated services provided, from a sustainability point of view. Redesign is an incremental, type of product innovation and typically involves smaller risks and investments. The D4S Redesign approach has 10 steps, that can be grouped according to the 4 basic steps for product innovation (goals and strategies, idea finding, strict development, and realisation) (Crul and Diehl, 2009).

Table 3-4 (continued): Brief description of the DfS models analysed in this paper (by chronological order).

Date	Author(s)	Designation	Short description
2009	Tischner et al. Tischner and Vezzoli	Product-service systems for Design for Sustainability: Pilot project and integration into company practice. (**PSS for D4S**)	Step-by-step approach for PSS development, focusing on a pilot project (Ursula Tischner et al., 2009) and on integration into company practice (Ursula Tischner & Vezzoli, 2009). Both references share exactly the same principles and methods, being the second an extension of the first one, thus presented together. They are organized in five phases, supported by tools and guidelines for the integration of environmental, social and economic aspects in developing effective combinations of products and services to fulfil the customers' needs. PSS for D4S is an update of the original Practical Guide for PSS Development, by Tischner and Tukker (2006).
2013	Gaziulusoy et al.	Systemic double-flow scenario method for companies (**SCENARIO**)	Scenario method that uses both explorative and backcasting scenarios to link activities/decisions at the product development (micro-innovation) level in companies with the transformation that needs to take place at societal (macro-innovation) level to achieve sustainability. The operational tool for the model is a workshop process (A. Idil Gaziulusoy et al., 2013).
2104	Fargnoli et al.	Design Management for Sustainability (**DMS**)	Environmental and user-centred procedure, where the goal of design activities is represented by the achievement of compliance with the requests of stakeholders involved in the product life cycle. It includes the use of a product design process and several design methods and techniques, based on an augmented Quality and Environment Function Deployment method. Applied with an Italian manufacturer of gardening equipment (Fargnoli et al., 2014).
2015	Joore and Brezet	Multi-level Design Model (**MDM**)	Design supportive model that (1) provides insight into the development of new products and PSS, as well as developments in society; (2) provides insight into the relationship between functional problems and abstract societal problems; (3) describes design, change and transition processes that can be used to structure future design-based initiatives. The MDM is based on four aggregation or system levels: (P) the product-technology system; (Q) the product-service system; (R) the socio-technical system; and (S) societal system. The application of MDM was simulated with sustainable transportation (Joore & Brezet, 2015).

Table 3-4 (continued): Brief description of the DfS models analysed in this paper (by chronological order).

Date	Author(s)	Designation	Short description
2018	Tao and Yu	Framework for sustainable product development in the context of high value engineering (**VALUE**)	Life cycle design methodologies for sustainable value creation, in the framework of a sustainable value model which is based on the understanding of the economic, environmental and social dimensions of value. The methodologies are organized as follows: life cycle design requirements (following sustainable value requirements); life cycle solutions (design concepts and life cycle plans generated by a quality function deployment- based approach); and life cycle simulation to evaluate sustainable value-driven designs. Applied to an electric soybean milk maker (Tao & Yu, 2018).

These ten models are distributed throughout 15 of the approximately 19 years covered by the literature review, with a peak on the period 2007-2009.

Out of those ten models, five are dedicated to product design (ROADMAP, MSPD+TEMPLATES, D4S REDESIGN, DMS and VALUE) and one (SPSD) is meant to cover product, service or product-service systems (PSS) design. Two other models have a PSS concern: PSS for D4S and SOP. As the expression "product-service systems" was not amongst the search terms in the literature review, there were very few related results and only two models, which were kept in the analysis in order to understand if they perform differently from the others, vis-a-vis the analytical framework proposed in this paper and given the variety of innovation levels represented by this selection. Finally, two models that were an outcome of the literature review include the intervention of de- signers in shaping societal changes: the SCENARIO and the MDM models, that aim at translating such systemic changes in the product-service design and are informed by system innovation theory (Gaziulusoy et al., 2013; Joore and Brezet, 2015).

3.4.1 Analysis of the models

Table 3-5 presents the results of the analysis of the ten models performed using the analytical framework developed in this research. A chronological order of presentation is followed, combined with their focus: product, product and/or service, PSS and system innovation.

Table 3-5: Presence or absence of the elements of the analytical framework in the analysed models, plus the indication of the aimed innovation scale.

		Strategic				Tactical				Operational
Models Acronym / Reference(s)		**Sustainability vision**	**Integration in the business strategy**	**Stakeholder involvement**	**Aimed innovation scale**	**Environmental, social and economic criteria**	**Sustainability assessment**	**Integration in management systems and practices**	**Involvement of different internal functions**	**Organization of the design and development process**
ROADMAP[(1)]	Waage, 2007	Yes	No	Yes	*Levels 1 and 2*	Yes	Yes	No	Yes	Yes
MSPD + TEMPLATES[(1)]	Byggeth et al., 2007 Ny et al., 2008	Yes	No	Yes	*Levels 1 and 2*	Yes	Yes	No	Yes	Yes
D4S REDESIGN[(1)]	Crul and Diehl, 2009	No	Yes	Yes	*Levels 1 and 2*	Yes	Yes	Yes	Yes	Yes
DMS[(1)]	Fargnoli et al., 2014	Yes	No	Yes	*Levels 1 and 2*	Yes	Yes	No	No	Yes
VALUE[(1)]	Tao and Yu, 2018	Yes	No	Yes	*Levels 1 and 2*	Yes	Yes	No	No	Yes
SPSD[(2)]	Maxwell and van der Vorst, 2003	No	Yes	Yes	*Levels 1, 2 and 3*	Yes	Yes	Yes	Yes	Yes
SOP[(3)]	Manzini et al., 2004	Yes	Yes	Yes	*Level 3*	Yes	Yes	No	No	Yes
PSS for D4S[(3)]	Tischner et al., 2009 Tischner and Vezzoli, 2009	Yes	Yes	Yes	*Level 3*	Yes	Yes	Yes	Yes	Yes
SCENARIOS[(4)]	Gaziulusoy et al., 2013	Yes	Yes	Yes	*Levels 1, 2, 3 and 4*	No	Yes	Yes	Yes	Yes
MDM[(4)]	**Joore and Brezet, 2015**	Yes	No	Yes	*Levels 1, 2, 3 and 4*	No	Yes	No	No	Yes

(1)Product improvement; (2)Product redesign; (3)Function innovation: Product-service systems design; (4)System innovation: Societal changes design.

Table 3-5 shows that all models contain elements of the strategic, tactical and operational levels, and thus are in accordance with what design management theorists advocate, as stressed in section 3.3.2.2. The only model that includes all elements of the analytical framework is PSS for D4S; D4S REDESIGN, SPSD, SCENARIOS and MSPD+TEMPLATES have a very good match. The model with the lowest correspondence to the framework is MDM, in whose description only four out of the nine elements are explicitly present. This indicates that the framework is applicable to models targeting the four innovation levels; the mismatch with the MDM may be explained by the perspective the authors adopted for the model, more abstract and less prescriptive than the others, and not necessarily by a conceptual incompatibility between MDM and the analytical framework.

At strategic level, one element is recurrent in all analysed models, which is stakeholder involvement. The next one that is most present is the establishment of a sustainability vision (in eight of the ten models). The integration of DfS in the overall business strategy is explicit in half of the models only.

As for the aimed innovation level according to Brezet (1997), five models concern levels 1 (product improvement) and 2 (product redesign) i.e., those that have been indicated above as product- focused; SPSD claims to be applicable to product and/or service development (levels 1, 2 and 3 e function innovation), whereas SOP and PSS for D4S are specifically meant for level 3. Two models concern all four innovation levels: SCENARIOS and MDM.

At the tactical level, the first element in the model concerns the integration of environmental, social and economic criteria in the design process. One of the conditions for a model found in the review to be included in the analysis was to have at least environ- mental and social considerations; however, in some cases it was observed that these considerations were not specified but formulated as a generic goal instead, and for this reason not considered as matching the framework: this was the case of SCENARIOS and MDM. On the other hand, sustainability assessment or evaluation of the new solutions (products, services or product-service combinations) is explicit in all models. As for the integration of DfS in management systems and practices, four models include it: D4S REDESIGN, SPSD, PSS for D4S and SCENARIOS. On what concerns the involvement of internal organizational functions in the design process, only four out of the ten models did not include this element.

Finally, the operational level: it is present in all models and variations in the way the design and development process is organized are described below.

3.4.1.1 DfS at strategic level

Establishment of a sustainability vision. All the eight models that include this element provide guidance on how to carry it out, varying from backcasting in ROADMAP and MSPD+TEMPLATES, to a combination of backcasting and forecasting (in SCENARIOS), to performing a sustainability SWOT analysis (PSS for D4S) or through multistakeholder processes (DMS, SOP, MDM and VALUE). The engagement of stakeholders to provide insights for the desired outcome in terms of sustainability has been researched and the role of stakeholders as legitimizers and concept refiners has been acknowledged (Evans et al., 2007; Goodman et al., 2017). Evans et al. (2007) argue that "one size fits all" solutions have proven not adequate for contributing to sustainability and that contextualization, as well as dialogue and negotiation with key stakeholders, are necessary.

One model adopts a normative stand by explicitly recommending the four principles for sustainability from The Natural Step (Robèrt, 2000) that were presented in section 3.3.2.1: the MSPD+TEMPLATES model. As for ROADMAP, it recommends that the company should choose a set of principles, such as The Natural Step, or sustainability strategies, such as the Natural Capitalism (Hawken et al., 1999), but does not prescribe a specific one. These overarching design rules can be considered "restrictive in comparison with the current way of organising production and consumption patterns" (Tukker, 2008, p. 19), so it is not surprising that the majority of the models do not include them.

The variety of solutions offered by the analysed models reflects the lack of consensus on how to operationalize sustainable development (Tukker, 2008; Pavlovskaia, 2014). Providing guidance on how to integrate a sustainability vision in the early innovation phase in product and service development is crucial and there is a need for developments in this area.

Integration in the business strategy. Only half of the models include this element, although it is a feature of companies that show a higher level of maturity in ecodesign according to Pigosso et al. (2013), and this applies to DfS as well.

Out of the five models that are explicit regarding the integration of DfS in the business strategy, three challenge the status quo in companies:

- PSS for D4S, by requiring an innovative culture capable of promoting new forms of organization and new external partnerships;

- SOP, through specific methods that question the potential for the company to innovate and its social and environmental sustainability awareness, at the initial phase of the process;
- SCENARIOS, by questioning the social function of the company in a sustainable society.

The other two (SPSD and D4S REDESIGN) focus on the alignment of DfS with existing goals and strategies. Whether or not these goals and strategies are sustainability-oriented is not discussed and this is a weak point as it may lead to a business-as-usual scenario where the sustainability potential of new solutions is limited.

Stakeholder involvement. Stakeholder involvement is referred to in all models and seven of them present guidance on mechanisms to do so. These vary significantly, from simply mapping and consulting stakeholders (indicated in the SCENARIOS model), to methods for consulting and providing feedback to stakeholders (this is the case of D4S REDESIGN and DMS) and to co- creation (PSS for D4S, SOP, ROADMAP and VALUE). They correspond to three levels of stakeholder involvement as proposed by Manetti (2011). In DfS, the higher level is considered necessary for sustainable product innovation (Morelli, 2007; Sanders and Stappers, 2008). Melles et al. (2011) propose that in a co-design approach to developing products, designers attempt to address the holistic needs of society as a whole and this, according to Evans et al. (2007), is not possible without all the parties involved.

As for priority stakeholders to involve in DfS, it is observed that seven models indicate the actors from the value chain, which is supported by several researchers (Govindan et al., 2014; Partidário, 2002; van der Heijden and Cramer, 2017). Three of those models go beyond the value chain and include other stakeholders, such as authorities, competitors and media (MSPD+TEMPLATES), knowledge institutions and sector/cluster organizations (D4S REDESIGN) and experts and analysts from different fields (PSS for D4S).

Aimed innovation scale. As already discussed and shown in Table 3-5, the analysed DfS models cover different innovation levels. Several authors argue for the need of addressing sustainability at the system level (Charter and Tischner, 2001; Spangenberg et al., 2010; Vezzoli and Manzini, 2008b), but as Ceschin and Gaziulusoy (2016) note, this does not mean that less systemic DfS approaches are not important, as higher-level innovations require "material artifacts that need to be properly designed" (p. 147). Both the SCENARIOS and MDM are important attempts to link the different levels.

3.4.1.2 DfS at tactical level

Environmental, social and economic criteria. It should be mentioned that it is difficult to clearly distinguish between environmental, social and economic criteria, as one criterion (e.g. reduce a product's energy consumption during the use phase) has clearly environmental (less greenhouse gas emissions), economic (less costs for the user) and social (higher equity in the ability to use the product) implications. Nevertheless, in the description of some models such distinction is made by the authors, which makes the analysis straightforward. In its absence, the ecodesign criteria (see e.g., Brezet and van Hemel (1997); van Hemel (1998)) is used for the environmental category, the ISO 26000 (ISO, 2010) core subjects (except 'the environment') are the guidance to classify social criteria and cost-related criteria are included in the economic category. Thus, the example above is considered an environmental criterion.

The element "environmental, social and economic criteria" of the analytical framework concerns criteria for generating improvement or innovation ideas; criteria for assessment are considered within the analytical element "sustainability assessment". However, it was observed that in several models the idea generation criteria and the assessment criteria are the same. Therefore, a joint analysis was performed, as presented in Table 3-6.

Table 3-6: Environmental, social and economic criteria in the analysed models.

Source: Own elaboration.

<table>
<tr><th colspan="2">Models
Acronym / Reference(s)</th><th>Environmental criteria</th><th>Social criteria</th><th>Economic criteria</th></tr>
<tr><td rowspan="2">ROADMAP</td><td rowspan="2">Waage, 2007</td><td>CRITERIA FOR DESIGN:
Broader system dynamics such as TNS system conditions and environmentally screened characteristics:
- Decreased flows and volumes of products and materials
- More sustainable materials
- Efficient, renewable and sustainable sources of energy</td><td>CRITERIA FOR DESIGN:
Broader system dynamics such as The Natural Step (TNS) system conditions and socially screened characteristics: enforced human rights policies for company and suppliers linked to Universal Declaration of Human Rights and International Labour Organization principles:
- Safe and wealthy working conditions
- Freedom of association
- Non-discrimination
- No forced or child labour</td><td>Not specified</td></tr>
<tr><td colspan="3">CRITERIA FOR ASSESSMENT:
The same as the criteria for design</td></tr>
<tr><td rowspan="2">MSPD+ TEMPLATES</td><td rowspan="2">Byggeth et al., 2007
Ny et al., 2008</td><td>CRITERIA FOR DESIGN:
Framework for Strategic Sustainable Development/The Natural Step conditions</td><td>CRITERIA FOR DESIGN:
Framework for Strategic Sustainable Development/The Natural Step conditions</td><td>CRITERIA FOR DESIGN:
None, the economic ones are considered traditional</td></tr>
<tr><td colspan="3">CRITERIA FOR ASSESSMENT:
The same as the criteria for design</td></tr>
</table>

Table 3-6 (continued): Environmental, social and economic criteria in the analysed models. Source: Own elaboration.

Models Acronym / Reference(s)		Environmental criteria	Social criteria	Economic criteria
D4S REDESIGN	**Crul and Diehl, 2009**	CRITERIA FOR DESIGN: - Selection of low impact materials - Selection of materials use - Optimization of production techniques - Optimization of distribution system - Reduction of impact during use - Optimization of product lifetime - Optimization of end of life systems		
		CRITERIA FOR ASSESSMENT: - Materials - Energy use - Solid waste - Toxic emissions - Water - Carbon dioxide emissions	CRITERIA FOR ASSESSMENT: - Social responsibility - Human resources management	CRITERIA FOR ASSESSMENT: - Distributed economies - Costs
DMS	**Fargnoli et al., 2014**	CRITERIA FOR DESIGN: Depending on the stakeholders and the results of the application of environmental assessment tools CRITERIA FOR ASSESSMENT: Not specified, the model recommends tools such as Eco-indicator 99 and the Ecodesign PILOT	CRITERIA FOR DESIGN: Depending on stakeholders, e.g. safety and design for all CRITERIA FOR ASSESSMENT: Not specified, the model recommends tools such as Preliminary Hazard Analysis (safety)	CRITERIA FOR DESIGN: - Internal and external costs CRITERIA FOR ASSESSMENT: The same as the criteria for design

Table 3-6 (continued): Environmental, social and economic criteria in the analysed models. Source: Own elaboration.

<table>
<tr><th colspan="2">Models
Acronym / Reference(s)</th><th>Environmental criteria</th><th>Social criteria</th><th>Economic criteria</th></tr>
<tr><td rowspan="2">VALUE</td><td rowspan="2">Tao and Yu, 2018</td><td>CRITERIA FOR DESIGN: This model distinguishes life cycle design requirements which are artefact-focused (not specified) and process-focused, the following:
- Resource efficiency in manufacturing
- Pollution and risk prevention in manufacturing, maintenance and end-of-life
- Convenience of product disposal
- Collection ratio
- Reuse and recycling ratio in the end of life
- Total residue/waste fraction in the end-of-life
- Hazard waste ratio and treatment</td><td>CRITERIA FOR DESIGN: This model distinguishes life cycle design requirements which are artefact-focused (not specified) and process-focused, the following:
- Professional risk prevention in manufacturing and end-of-life
- Job creation in manufacturing, maintenance and end-of-life</td><td>CRITERIA FOR DESIGN: This model distinguishes life cycle design requirements which are artefact-focused (not specified) and process-focused, the following:
- R&D budget
- Profits expectation of the manufacturer, retailer, service provider and recycler
- Product ownership and use cost
- Collection and disposal costs</td></tr>
<tr><td colspan="3">CRITERIA FOR ASSESSMENT:
Similar to the criteria for design, organized in three sub models: stakeholder model, product model and process model</td></tr>
</table>

Table 3-6 (continued): Environmental, social and economic criteria in the analysed models. Source: Own elaboration.

Models Acronym / Reference(s)		Environmental criteria	Social criteria	Economic criteria
SPSD	**Maxwell and van der Vorst, 2003**	CRITERIA FOR DESIGN: - Amount, nature/hazardousness and renewability of materials - Waste and emissions - Energy use - Type of fuel used in transport	CRITERIA FOR DESIGN: - Are raw materials extracted/processed in the developed world? - Ownership rights - Equitable trading arrangements - Employee conditions and health and safety at work - Impact and investment for local community - Health and safety local and global community	CRITERIA FOR DESIGN: - Cost-effectiveness of products and services - Cost of the product and service compared to competition - Are environmental externality costs taken into account?
		CRITERIA FOR ASSESSMENT: The same criteria as those for design		
SOP	**Manzini et al., 2004**	CRITERIA FOR DESIGN: Not specified - they are implicit in the sustainability criteria for the assessment phase		
		CRITERIA FOR ASSESSMENT: - Material use - Energy use - Water consumption - Transport - Land use - Waste - Wastewater - Global warming	CRITERIA FOR ASSESSMENT: - Experience with the PSS - Timing - Variety and choice - Shopping/delivery - Quality - Knowledge	CRITERIA FOR ASSESSMENT: - Life cycle costing

Table 3-6 (continued) – Environmental, social and economic criteria in the analysed models. Source: Own elaboration.

Models Acronym / Reference(s)		Environmental criteria	Social criteria	Economic criteria
PSS for D4S	**Tischner et al., 2009 Tischner and Vezzoli, 2009**	CRITERIA FOR DESIGN: - System life optimization - Transportation/distribution reduction - Resources reduction - Waste minimization/valorisation - Conservation/biocompatibility - A-toxicity	CRITERIA FOR DESIGN: - Sufficiency - Health and safety - Living conditions/quality of life - Employment/working conditions - Equity and justice/relation with stakeholders - Respect cultural diversity	CRITERIA FOR DESIGN: - Market position and competitiveness - Profitability/added value for companies - Added value for customers - Long term business development/risk - Partnership/cooperation - Macro-economic effect
		CRITERIA FOR ASSESSMENT: The same as the criteria for design, with different guiding questions and scoring system		
SCENARIOS	**Gaziulusoy et al., 2013**	Not specified		
MDM	**Joore and Brezet, 2015**	Not specified		

From the eight models that are explicit regarding this element of the analytical framework, six comprised environmental, social and economic criteria for design, whereas two of them excluded the economic dimension: In the MSPD+TEMPLATES method, the reason for this is that economic criteria are considered "traditional" (Byggeth et al., 2007, pg. 2), i.e., criteria that are part of the design process when sustainability is not a concern. But as van Bommel (2011) notes, the interest in the "prosperity" aspects of sustainability is not because these aspects are new, "but because they are now becoming part of a wider corporate social responsibility/sustainability approach" (p. 897). As for ROADMAP, the three dimensions are mentioned throughout the explanation of the model, but when it comes to specifying criteria, the economic ones are absent.

Environmental criteria tend to be more emphasized than the social and the economic ones, either in the sense they are more numerous and detailed or because they are more directly related to product or service performance, whereas the other dimensions are addressed in a vaguer way: for instance, in the D4S REDESIGN model, one social criterion is broadly defined as "social responsibility" and one economic criterion is "distributed economies". This is not surprising given the roots of DfS in ecodesign (Ahmad et al., 2018), but this is certainly an aspect to be improved. To be noted that criteria such as "social responsibility" or "human resources management" relate to company practices (including those of suppliers') and not to properties of the product or service. On the contrary, the DMS model includes as a social criterion "design for all", which reflects a social concern (no discrimination) as a product feature.

Both product-related social criteria and process-related social criteria are important for the development of socially sustainable products (Hanusch and Birkhofer, 2010; Howarth and Hadfield, 2006). The process-related ones allow identifying the responsibilities of all departments involved on the entire product creation process (Hanusch and Birkhofer, 2010). However, as these authors stress, there should be a distinction between the two types of criteria; such distinction is not observed in the analysed models. The use of the social responsibility standard ISO 26000 (ISO, 2010) and its core subjects and issues to derive workable socio-economic criteria for DfS has been performed (Hanusch and Birkhofer, 2010; Rocha and Schmidt, 2014; Vicente et al., 2010). Rocha and Schmidt (2014) proposed a comprehensive list of aspects that are conceptually part of DfS and it was possible to identify design strategies that are already being practiced to address various issues, such as:

- Universal design (fighting discrimination);

- Design for the "base of the pyramid" (fighting poverty);
- Design for health and safety at the workplace (avoiding the use of hazardous substances and dangerous manufacturing equipment);
- Design for sustainable consumption (e.g., increasing product durability);
- Co-creation with the community (supporting socio-economic conditions of local communities).

The models that showed a stronger adherence to this type of approach are SPSD and PSS for D4S.

Hence, there is a clear need of further developments in the social component of DfS. It is remarkable that the level of detail in providing guidance on design criteria related to the three components of sustainability does not seem to be related with the date of development, whereas more recent models could be expected to have this question better worked out, given the progress in aspects of sustainability management in recent years. A review of literature on the business case for corporate social responsibility showed a remarkable increase of publications from 2009 onwards (Wójcik, 2018).

Authors such as Arnette et al. (2014), Gmelin and Seuring (2014), Buchert et al. (2015) and Hallstedt (2017), indicate that the main reason for the social dimension of DfS to be less developed is the more recent development of social life cycle assessment and social indicators for products, when compared to the other dimensions of sustainability. In contrast, Link et al. (2013) argue that designers have a much lower influence on social sustainability than on the environmental and economic dimensions.

As for trade-offs between criteria, although most models mention this aspect, only one provides guidance on how to tackle them: ROADMAP, through the focus on critical sustainability impacts and having broad sustainability principles as guiding principles. This is a clear weakness, since designers would always face situations when alternative solutions emphasize different sustainability aspects that have to be balanced against each other (Byggeth and Hochschorner, 2006) and they need support for decision making. This result is corroborated by research conducted in ecodesign (Prendeville et al., 2013) and is even more relevant when other variables beyond environmental ones come into play. Gibson (2013) highlights that the usual approach is to assume that trade-offs are inevitable and that within such a view the good practice is to make trade-offs explicit for better-informed choices, although the general objective should be to avoid trade-offs of any kind for a meaningful progress towards sustainability.

In any case, in order to deal with the trade-offs that may occur on DfS, may it be through mitigation or through finding out-of-the-box solutions that eliminate those trade-offs, assessment tools are necessary, and the way the studied models deal with them is presented in the next paragraph.

Only four of the models under analysis specify DfS strategies and they are closely related to the design criteria set up by them. The exception is the D4S REDESIGN model, which presents eight strategies widely used in ecodesign (Brezet and van Hemel, 1997; van Hemel, 1998), to which socially-related sub-strategies are added, such as health and safety in relation to production or preference for local materials (see Table 3-6).

The SPSD model is also detailed regarding design strategies, following a DfX (design for repair, design for recycling) approach, but only environmental ones can be found. The PSS for D4S model's strategies coincide with the social, environmental and economic criteria and ROADMAP proposes overarching strategies such as "substitute", "dematerialize", "humanize" or "improve human health and fulfil human needs".

There is clearly room for development and further research when it comes to DfS strategies (Kälkäjä, 2016), in order to balance the three dimensions of sustainability, and even to characterize and understand the existing typologies. The studied models provided a very disparate picture, confirming that DfS is still at an early stage (Gmelin and Seuring, 2014).

Sustainability assessment. As mentioned in 3.4.1, all models include the element of sustainability assessment, and out of these, eight include details on how to perform it. The exceptions are MDM and SCENARIOS. In the case of the latter, "products can be regarded as 'sustainable' only if the socio-technical system within which they are produced and consumed is a sustainable one. Thus, any product ideas generated from this method would need the assessment of their environmental and social performance" (Gaziulusoy et al., 2013, p. 114-115); but no further guidance is provided.

All remaining models recommend some sort of life cycle evaluation. Despite of the importance of full life cycle assessments in accordance to ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b) methods (Guinée et al., 2011), problems are encountered when applying them to product development, especially the early stage of the process, when there is not enough specified information to perform the study (Chang et al., 2014). Thus, quantitative-oriented methods are used retrospectively when the design process is nearly completed (Buchert et al., 2015).

Therefore, it is not surprising that almost all models recommend qualitative or semi-quantitative methods based on matrixes or checklists, although concerns about their excessive broadness to be helpful to support design decisions exist (Buchert et al., 2015). The exception is DMS, which indicates screening LCA tools, such as the Ecodesign PILOT (Wimmer and Zust, 2001) or quantitative LCA methods such as the Ecoindicator 99 (Goedkook and Sprinensma, 2001) for the environmental component of the assessment. The SPSD model advocates for qualitative assessment, complemented by abridged LCA. As for the VALUE model, it proposes a life cycle simulator based on discrete-event system simulation theory, which quantifies the product performance against a list of requisites at stakeholders, product and process levels.

Integration in management systems and practices. The link between ecodesign and design for sustainability and organizational management systems, as a condition for longer term and system- atic implementation (as opposed to the DfS efforts being isolated, ad-hoc activities) has been recognized for a long time (Charter and Tischner, 2001; Lindahl, 2005; Rocha and Brezet, 1999; Stevels, 2009).

Four of the studied models mention the aspect of integration in management systems and practices, but only three specify how to do it:

- D4S REDESIGN and SPSD recommend linking DfS with management systems; D4S REDESIGN provides extensive guidance on the integration process, using SWOT analysis, a plan-do-check-act method and a method for the creation of a communication plan;
- The PSS for D4S model amply develops this issue, through the awareness of the management function, the appointment of product-service systems steward(s), integrating PSS thinking into the normal activities and tools, training specific staff, using the tools provided on a regular basis, setting up external cooperation and setting up internal and external communication.

Involvement of different internal functions. This is another element that shows a good scoring in the models that were studied in this research, which is in accordance with Link et al. (2013) and Gmelin and Seuring (2014), who argue that interdepartmental work is a success factor for new product development. Out of the seven that include this issue, five indicate explicit functions that are related to DfS, one calls for concurrent engineering and it is up to the company to decide the adequate functions (MSPD+TEMPLATES) and another one does not specify any functions (SCENARIOS).

The most mentioned function was marketing (four models), followed by sustainability-related management functions (three), purchase, finance and production/engineering (two each, not coincidentally).

Already in 2000, Rossi et al. concluded from the 1999 Greening of Industry Network Conference, that multinational corporations defining the sustainability agenda implement it through technology innovation, production and product marketing. As a matter of fact, according to Luttropp and Lagerstedt (2006) marketing, design, production and purchasing are functions that together form the product development teams. Link et al. (2013) found out that the most influential functional areas for sustainable product development are management, R&D, production, marketing/distribution, procurement, materials logistics, human resources, and technical after-sale service. They further state that this influence is stronger in the environmental and economic dimensions, when compared to the social dimension.

3.4.1.3 DfS at operational level

Organization of the design and development process. There is only one model (SOP) that does not include a stepwise approach for (in this case, PSS) design, but rather an open and iterative framework. Nevertheless, if offers some sort of structuring of the design process. The remaining models explicitly include stages, with varied approaches, but typically starting with the understanding of the system, or the needs to be fulfilled, followed by the development of concepts, the detailed design and the implementation. According to Lawson (1997), the design process as a sequence of activities is questionable, as they would not occur in order or would even be identifiable separate events; attempting to map the design process is always a simplification of a highly complex design problem. Ulrich and Eppinger (2000) defend that structured design methods are valuable by making the decision process explicit, by making sure that important issues are not forgotten and because they are self-documenting and the record of the decision-making process is important for future reference. In any case, the adaptation of the stages proposed in the models to the design process already existing in companies is desirable and even recommended, for instance in the MSPD+TEMPLATES model.

Another question that interested this research was the need to adapt the design and development process to address sustainability considerations. The most remarkable finding was the addition of an explicit activity of questioning the function, or the need, that the product or product-service combination should fulfil. Functionality thinking is a well-known characteristic of design (Demirbilek and Park, 2001) and an opportunity to innovate towards more sustainable solutions in eco-design and design for sustainability (Stevels, 2009). Five models explicitly included this element: SPSD, ROADMAP, MSPD+TEMPLATES, SOP and PSS for D4S.

3.4.2 Overall analysis of the framework and of the results

The analytical framework, composed of nine elements organized in three levels of DfS implementation (strategic, tactical and operational) and with 22 subordinate questions derived from design management and corporate sustainability theories, seemed to be appropriate, for two main reasons:

- Firstly, because it fit the description of the models and captured their main components;
- Secondly, because it was possible to compare the findings with a large amount of literature in the field and, in many cases, to corroborate them.

It seems, therefore, that the framework gives a useful contribution to understand how DfS implementation is advocated on a theoretical level. Despite the fact that out of the ten analysed models, six included a description of practical implementation (SPSD, SOP, MSPD+TEMPLATES, DMS, MDM and VALUE), the analysis focused on the theoretical part of the respective publication; in this way, the treatment of models with and without case studies was comparable.

The fact that it was possible to deal with uncertainties that arouse during the analysis phase to match very different models to the elements of the framework does not mean that they are easy to understand and implement. On the contrary, the models are, in most cases, complex and require an external expert that masters the method to guide the implementation. The challenge of tackling a complex subject such as DfS in a way that is accessible to organizations is far from accomplished, according to the results of this research.

A simple count of the "yes" cells in Table 3-5 indicates that the numbers of elements of the framework that are present in the models are similar in the strategic and tactical levels

(23/30 and 28/ 40 or 77% and 70%, respectively). The operational level, with one element only, was present in all models.

The more insightful analysis provided by the 22 questions has led to a better understanding of the studied models. Aware of the risk of added subjectivity, Fig. 3-4 was elaborated to provide an overview of the development and consensus levels of the models, regarding the framework:

- Development is related to the amount of guidance that is provided by the models;
- Consensus is related to the similarity of the guidance provided by the models.

Fig. 3-4 should be read as complementary to Table 3-5, since this figure is built upon the details of the guidance provided by the different models and the table indicates simply the presence or absence of a given element. As a simple direction on how the figure should be read, consider e.g., the exemplary case that is the establishment of a sustainability vision for DfS, where almost all models provide detailed guidance on how to perform it (high level of development); however, the proposed related methods show a significant variation (low level of consensus).

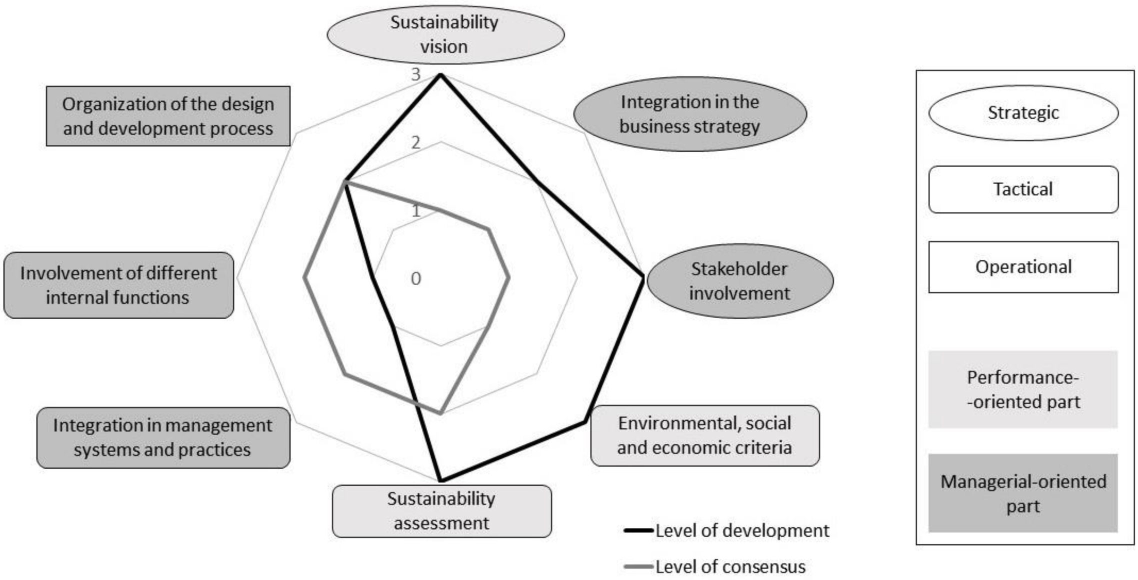


Figure 3-4: Levels of development and consensus in the ten DfS models regarding the framework's elements. Source: Own elaboration.

On the strategic and tactical levels, it is noticeable that setting a sustainability vision, establishing social, environmental and economic criteria and carrying out sustainability assessment to support the DfS process at different stages are the most developed elements, i.e., the performance-oriented part of DfS (or, in the words of Henri and Journeault (2010), related to results); the consensus on how to do it, however, is not achieved. The managerial or process (Henri and Journeault, 2010) elements (including the organization of the DfS process) are less developed but more consensual at the tactical and operational levels.

It is not expected that the models are consensual in all elements; otherwise, one standard model would suffice. But it would be important to have a clearer understanding of which implementation methods would be more appropriate, according to the objectives of the project and its innovation level, considering the company, its value chain and wider societal challenges. In view of the results of this research, the priority should go to:

- Establishing a sustainability vision for DfS, based on the state-of-the art knowledge of sustainability challenges and considering the specificities of the product, service, PSS or system;
- Integration of DfS in the business strategy at the highest level, triggering sustainable organizational innovation;

- Stakeholder involvement towards co-creation;
- Environmental, social and economic criteria for DfS, addressing the shortcomings in relation to the social dimension and dealing with trade-offs;
- Sustainability assessment of the new solutions, through a combination of qualitative and quantitative indicators that are adequate to the different phases of the DfS process and enable to follow-up the progress towards the sustainability vision.

3.5 Conclusions, limitations and perspectives for future work

Arnette et al. (2014) claim that "the application of theory and building theoretical frameworks" (p. 386) for research in the field of DfS is the most important effort to be undertaken by researchers, in order to advance the body of knowledge. The results achieved with this paper, which were systematically contrasted with other published research, give the confidence that the framework and review here presented may contribute to that effort.

The use of corporate sustainability management and design management as theoretical foundations to draw a framework for analysis of the reviewed models has shown to be adequate, since it captured most of their features, and allowed also to understand how they varied in the approaches used to put DfS into practice, at strategic, tactical and operational levels, as well as to identify gaps and common elements.

A comprehensive picture of the state of the art regarding conceptualizations and methodological approaches to DfS was drawn, through the in-depth analysis of ten DfS models published in the literature between 2000 and 2019. It showed that there is a serious attempt to support companies in implementing DfS, not only for products, but also for services and PSS development and even to sustainability-oriented system innovation, as well as crossing over various innovation levels.

This research indicated that, on a conceptual level, DfS has evolved and matured; however, this is not the case as for DfS operationalization. What does "for sustainability" mean when it comes to putting DfS in practice? The analysed models do not show consensus on how to answer this question e neither on the overarching vision and principles to follow, nor on the environmental, economic and especially social strategies and criteria to apply, nor on how to assess the results achieved. Given the importance of design in sustainable consumption and production, this is a drawback that future research needs to address.

From the environmental sustainability side, one possible contribution to such endeavour is to explore the relationship between DfS and circular economy, a concept that is high in the political and academic agendas, since it is considered as a promising path to a potential solution to foster environmental protection without limiting economic growth (Lieder and Rashid, 2016; Stahel, 2016). So far, the notion of circular economy has referred primarily to the most technically-focused DfS approaches (covering various innovation levels from materials to products, business models and industrial systems), with a limited emphasis on user practices and behaviours (Ceschin and Gaziulusoy, 2016) and in the social aspects of sustainability (Murray et al., 2017). Despite this, some authors note that circular economy provides a clear angle of attack to address environmental concerns (Sauvé et al., 2016) that was lacking when tackling sustainability in a linear model paradigm and thus may provide an important contribution to DfS.

The confirmation that the social dimension in DfS lags behind raised several questions: What is the role of design in promoting social sustainability? Will future developments in social life cycle assessments and social indicators for products lever socially sustainable design? Will a better alignment of social responsibility and DfS support overcoming this difficulty?

The results obtained with the analytical framework adopted in this study are of course limited by the models that were selected for review, which include some degree of subjectivity regarding the application of exclusion criteria in the literature review.

This article has a markedly theoretical character, since only academic models have been researched. Some companies have been applying DfS and the approaches they followed have been published in the literature (see Charter and Tischner (2001), Stevels (2009), Petala et al. (2010) and Ghadimi et al. (2012), for instance), but for reasons of workability the decision was to focus on theoretical developments only. One promising avenue for future research would be to apply the analytical framework developed in this paper to companies engaged in DfS and study their practices in view of the framework and of the results of the research here presented.

Future efforts to support DfS implementation should focus primarily on performance-oriented aspects and on strategic aspects. The managerial elements of the framework, at tactical and operational levels, seem to be better resolved by the analysed models.

Acknowledgements

The authors gratefully acknowledge the valuable comments and suggestions made by the anonymous reviewers who contributed to improve an earlier version of this article. CENSE is financed through the Strategic Project UID/AMB/04085/2019, of the Fundação para a Ciência e Tecnologia, Portugal.

4

CIRCULAR DESIGN STRATEGIES[4]

4.1 Introduction

Circular economy (CE) is about "maintaining the function and value of products, components, and materials at the highest possible level and extend their lifespan". The right combinations of product and service design strategies support circular economy by (Bocken et al., 2016):

- Closing resource flows: through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources;
- Slowing resource flows: the utilization period of products is extended and/or intensified, resulting in a slowdown of the flow of resources;
- Narrowing flows: using fewer resources per product or service unit.

Figure 4-1 illustrates the closing, slowing and narrowing resource flows that is demanded by CE and the implications for product and product-service systems (PSS) design and development will be discussed. It should be noted that for these products and services to be successful in the market, companies need to develop adequate business models.

---

[4] *Extract and adaptation from the book chapter developed in the framework of the KATCH_e project – Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability in Higher Education (project nº 575793-EPP-1-2016-1-PT-EPPKA2-KA):*

Rocha, C. S., Camocho, D., & Alexandre, J. (2020). Design and development. In C. S. Rocha, D. Camocho, J. Sampaio, & J. Alexandre (Eds.), Product-Service Development for Circular Economy and Sustainability Course (pp. 238–293). LNEG - Laboratório Nacional de Energia e Geologia, I.P.

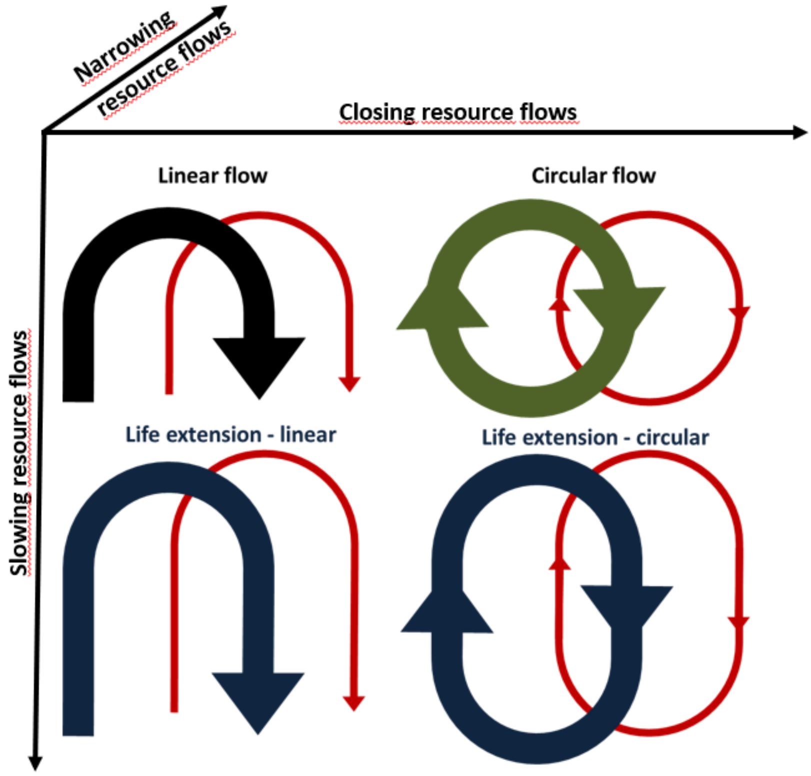


Figure 4-1: Categorization of linear and circular approaches for reducing resource use.

(Bocken et al., 2016)

The KATCH_e project proposes to adopt an integrative approach to the concept and practice of design for the circular economy. Unlike most publications and experiences in the field, that focus on slowing and closing resource loops (and disregard the dimension of narrowing loops since it applies also to a linear model) and do not consider the social dimension of sustainability, the KATCH_e project adopted the following definition:

Design for circular economy is a product-service design and development that replaces conventional end-of-life concept by closing, slowing and narrowing the resource flows in production, distribution and consumption processes. It is enabled by innovation and novel business models and aims to accomplish sustainable development through supporting ecosystem functioning and human well-being, and through responsible production and consumption.

When it comes to product and service design, what do "slowing loops", "closing loops" and "narrowing loops" mean? Table 4-1 presents examples of design approaches to make products more durable, to avoid that they become waste and to increase their use of resources. These approaches and strategies are further developed in section 4.3.

Table 4-1: Product design approaches for the circular economy

Product design approaches to slow loops = Design for durability
– To design long-life products – To foster a strong product-user relationship – To produce resistant, easy to maintain and repairable products – To use modularity, to allow the upgrading and adaptation of products
Product design approaches to close loops = Design for recycling
– To develop products in such a way that the materials can be continuously and safely recycled into new materials and products – To use safe and healthy materials for those products that are consumed or worn during use, and thus create food for the natural systems – To make it easy to dis- and reassemble products
Product design approaches to narrow loops = Design for resource conservation
– To use a preventive approach in which products and services are designed so that resources use is minimized in the whole life cycle – In addition to quantity, to choose more sustainable materials and energy sources when designing a product or a service

Design for the circular economy or circular design takes a new angle when dealing with environmental considerations in design:

- Inspiration by natural systems, where materials flow in cycles and there is no waste - everything should be a nutrient in the biosphere and the technosphere; this is a step forward, compared to previous approaches like ecodesign, which assumed that all products inevitably become waste at a certain point in time;
- Dematerialization, through the transition from selling products to providing services or product- service system solutions that drastically reduce the intensity of materials per unit of service provided (see the section on product-service systems);
- "More good instead of less bad": unlike in a traditional eco-design approach, which focuses on eco- efficiency with the goal of minimizing the cradle-to-grave flow of materials, circular design aims at eco-effectiveness, i.e. the transformation of

products and their associated material flows so that they form a supportive relationship with ecological systems and future economic growth (Ellen MacArthur Foundation, 2015). The aim is to have a positive impact. As a matter of fact, eco-efficiency is necessary but needs to be coupled with other strategies to counteract potential rebound effects (selling more products, even if each one is more eco-efficient, may result in a greater environmental impact);

- 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. Replace or treat only the smallest possible part to maintain the existing economic value of the technical system" (Stahel 2010, 195). The starting point for designers is the original products, it is about product integrity. On the other hand, in ecodesign one of the guiding principles is the waste hierarchy, in which the definitions of prevention (the preferred option), reuse, recovery, recycling, and disposal (the least preferred option) all are based on the assumption that eventually a product becomes waste, and a priority order for managing waste is provided. This focus on waste does not make sense in a CE (den Hollander et al., 2017) because, theoretically, the phase when a product is disposed of does not exist and after its use, all materials should be incorporated in the loop;
- Systems thinking: circular design elevates design to a systems-level (van den Berg and Bakker, 2015). This means understanding the complex and interconnected nature of any system of which a product is part, e.g. by identifying all components and material inputs in the life cycle, the ways the natural systems are impacted and the stakeholders involved (including the users), and understanding how decisions regarding such product interact with the wider system (British Standards Institute, 2017). Systems thinking can help designers to manage complexity more effectively (British Standards Institute, 2017) and avoid the negative consequences of poor planning.

4.2 Product-service systems

The product-service systems (PSS's) concept has been a matter of great attention for sustainability experts due to its potential to decouple revenues from material flows and to increase resource productivity. In other words, whereas in the traditional product-oriented business model, the company revenues depend on the number of units sold (and the pressure to continuously grow in sales leads to unsustainability), in a service-oriented business model the company sells a result or an access and owns the products: the less products they need, or the longer the products last with good quality to provide the service, the better for the company. Product-service systems have a high potential for circularity and sustainability (if developed with circular and sustainability criteria) and are based on business models which deliver added-value products and services that meet the needs of users more sustainably. In these systems, the focus is in the service that the user receives from a product and on the way the customer uses a product's function, rather than on the product itself. This systemic approach has a crucial role in the transition to a more circular economy.

PSS's are an innovative approach to sustainable business and may allow a company to (Crul and Diehl, 2009):

- Identify new markets and ways to profit; Survive and adapt to rapidly changing markets;
- Increase efficiency and reduce resource consumption;
- Compete in the market and generate value and social quality, while decreasing total negative environmental and social impact (directly or indirectly).

To implement circular economy in practice, focusing on an efficient transition from the linear model to a circular model, the way users' needs are fulfilled needs to change and innovative systems and business models have to be created. In this context, innovation is considered to be fundamental in guiding businesses towards a transformation of practices influenced by the design and functions.

PSS's are not a new concept, but when properly designed they have the potential to change production and consumption patterns towards a circular and sustainable future. Figure 4-2 offers a possible systemization of PSS's.

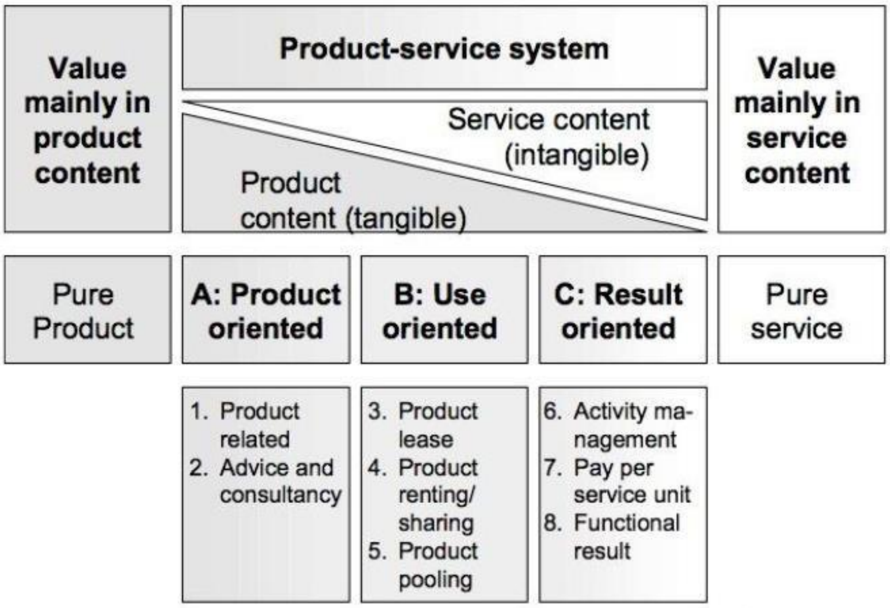


Figure 4-2: Eight types of PSS's

(Tukker, 2004)

Several categories of PSS's can be identified and the distinctions among the different forms are based on the extent of product ownership, the type of products involved, and the value-added of the service level (Tukker et al., 2006). The expression PSS highlights that there are neither "pure products" nor "pure services", but rather combinations of both. For simplicity, from this point onwards this section refers simply to services instead of PSS's, disregard the weight of the tangible or the intangible component.

Category A: **Product-oriented services**. Here, the focus is still mainly geared towards sales of products that are owned by the user or consumer, but some extra services are added.

Category B: **Use-oriented services**. The traditional product still plays a central role, but the business model is not geared towards selling products. Product is owned by the service provider who sells functions instead of products, through modified distribution, payment systems and sometimes the product is shared by several users.

Category C: **Result-oriented services**. Here, the client and provider agree on a result, and there is no pre-determined product involved.

Table 4-2: Categories of product-service systems with examples.

Sources: Tukker, van den Berg & Tischner, 2006; Tukker (2004)

Category A: Product-oriented services - The product is owned by the user/consumer
Product extension service, the value of a product is increased through additional services, e.g. upgrading, repair, guarantees, financing schemes, the supply of consumables, etc. **Advice and consultancy** concerning the most efficient use of the product. **Vertical Integration**, meaning modified delivering strategies to supply products to customers, retailers and/ or customers who get directly involved in the process of production, e.g. production on demand.
Category B: Use oriented services - The product is owned by the service provider who sells functions instead of products, through modified distribution and payment systems
Leasing. The provider retains ownership and is often responsible for maintenance, repair, and control. The leaser pays a regular fee for the use of the product and normally has an individual and unlimited access to the leased product. **Renting or sharing**, similar to leasing but the user does not have unlimited and individual access to the product. The same product is sequentially used by different users. **Pooling**, which is similar to sharing but there is a simultaneous use of the product.
Category C: Result oriented services - There is not a pre-determined product involved in this category
Activity Management, the supplier gives incentives for the customer to consume more efficiently and optimises a system e.g., by using modified payment systems, e.g., contracting. **Pay-per-service unit**, the user buys the output of the product e.g., pay per lux by Philips, a service in which the user buy light, and nothing else. **Functional result**, products are substituted by new solutions; the delivery is a result which is not related to a specific technology system anymore. Examples are pest control service instead of pesticides, delivery of a "pleasant climate" instead of selling heating or cooling equipment, etc.

4.3 The role of design in circular economy

"We don't have a waste problem, we have a design problem"

Michael Braungart and William McDonough, Founders of the Cradle2Cradle concept

Design plays a crucial role in circular economy and this is not only about recycling, but also about maintenance, repair, sharing, reuse, refurbishment and remanufacturing. Design has the power of enabling or hindering these features. It determines the circularity potential of products, services and systems. Traditionally, designers would focus exclusively on products, but their role is evolving. The power of design lies on its ability to ask fundamental questions, such as: What is the real purpose of this product? Which is the need that this product fulfils? Are there other solutions to respond to such need, e.g., through a service? Is it possible to increase well-being and happiness through this design? Does this design have a negative impact on the environment? A zero one? A positive one, contributing to the regeneration of ecosystems? And in society? (De Groene Zaak & Ethica, 2015).

Traditional manufacturing is wasteful because it focuses exclusively on the end-user. The circular economy mind-set looks much wider, to consider everyone who extracts, builds, uses, and disposes of things. By zooming out from users, to consider the wider network of stakeholders, we can unlock value at every stage of the process. As a designer, that includes building feedback loops into your work; knowing the life cycle of materials you use; collaborating with other industry stakeholders; and considering unintended consequences (Ellen MacArthur Foundation & IDEO, 2017).

Given that the design of a product directly influences the way a value chain will be managed, building circular, globally sustainable value chains inevitably signifies a fundamental change in the practice of design. A variety of new capabilities are key to design for a sustainable future; these range from a deeper knowledge of material composition to a rich understanding of social behaviour (De los Rios and Charnley, 2017).

Many examples illustrate the role of design in a circular economy. One interesting case comes from the British company CRISSCROSS Furniture Ltd. (Crisscross Furniture, n.d.). They offer modular, flat-pack furniture, whose main novelty relates to the easiness of assembling and disassembling and the possibility of reconfiguring the furniture. The furniture collection, designed by Sam Wrigley, comprises cupboards, wardrobes, a bedside table and desk. They are assembled using modules that are slotted into pre-existing holes in the boards and can be fixed in place without the use of any tools, allowing them to be easily removed and reused.

The relevance of this example, from the point of view of circular design, relates to:

- The use of eco-friendly materials: birch plywood from sustainable FSC© certified forests and natural plant-based wood waxes;
- The durability of the products: they are made of high-quality materials; in order to endure frequent use and disassembly, the brackets, hinges, and locknuts are made from high-grade aluminium that is anodised black. Furthermore, the easiness of disassembly and re-assembly with different configurations and without the need of tools gives the possibility of adapting the furniture to different needs and spaces over time;
- The recyclability: the products and packaging are 100% recyclable.

Figure 4-3: CRISSCROSS furniture.

Source: http://www.crisscrossfurniture.com/

Product design determines the circularity potential of a product because it establishes to a large extent its characteristics and features, which is the functionality, which materials are used in the product, how long it is supposed to last, its reparability and recyclability, etc. However, whether or not this potential is realised depends on how the product is managed throughout its life cycle (European Environment Agency, 2017).

The circularity of a product depends not only on its intrinsic properties but also on the system in which the product is integrated (European Environment Agency, 2017). For instance, the reparability of a product comes into effect if there are repair services and proper business models in place.

Finally, it is necessary to design products that can be reused, repaired, refurbished, remanufactured, repurposed, recycled and recovered.

Table 4-3: Design strategies for developing circular solutions

Aims regarding resource loops	Strategies
Slowing	Design of long-life products(1) Design for product-life extension(1) Design of product-oriented services(2) Design of use- or result-oriented services(2)
Narrowing	Design for materials sustainability(1) Design for energy sustainability(1)
Closing	Design for remanufacturing(1) Design for recycling(1)

Note: (1) product design; (2) service design

Fig. 4-4 presents the design strategies for circular economy developed within the KATCH_e project, organized according to the aims regarding resource loops and phases of the life cycle they relate to.

Phase	KATCH_e design strategies for a circular economy		
	Slowing loops	Narrowing loops	Closing loops
Uphill			
Tophill	Design of long-life products (1) Design for product-life extension (1) Design of product-oriented services (2) Design of use-oriented or result-oriented services (2)	Design for materials sustainability (1) Design for energy sustainability (1)	
Downhill			Design for recycling (1) Design for remanufacturing (1)

Note 1: (1) product design; (2) service design

Figure 4-4: Design strategies for a circular economy.

It should be noted that the strategies related to narrowing loops stem from the eco-efficiency paradigm and should always be used in combination with those from slowing and closing loops, as they are complementary. In other words, it does not make sense to design a long-life product without caring for the energy and materials (including water) sustainability along the life cycle. This idea is illustrated in Fig. 4-5, where the strategies are distributed along a simplified version of the products' life cycle, also known as the "Value Hill" (Achterberg et al., 2016): (i) Up-hill - before use (encompassing extraction of raw materials, manufacturing, assembly and retail), (ii) Top-of-the-hill - during use and (iii) Down-hill - after use (including reuse, refurbish, remanufacture and recycling - and eventually final disposal). The figure shows the most direct relationship, but one should keep in mind that potentially the entire life cycle is affected by each of the strategies - for instance, moving from a product to a service approach, although it concerns the use phase because the use/consumption model is changed, may lead to less products needed for the same function, which means fewer resources extracted and processed, less waste, etc.

4.3.1.1 Strategies for slowing resource loops

Design of long-life products

Currently, in most design projects the material efficiency component (that is, designing products with less material) is already considered as it is directly related to the costs reduction, thus being considered good commercial practice for companies (Bakker et al.,2014). On the other hand, the product life and product recycling are not usually considered in a design project (Hatcher et al., 2011).

The feasibility of long-life products in a business context and the associated consequences for product design, have remained largely unexplored (den Hollander & Bakker, 2012); however, there are several ways to extend the useful life (and value) of a product that designers should consider strategically in their projects.

The design of the products in this strategy has as the main goal, the durability of the product considering technological and emotional aspects in different levels (Bocken et al., 2016; Gerrittsen, M., 2015).

At a technological level, the design should consider:

- the durability of materials and processes;
- the durability of components and the relations between components;
- the technical solutions that allow a physical performance of the product during a long time without the need for maintenance or repair actions;

At an emotional level, the design must consider the relationship between the product and the user for a longer time. This kind of solutions should consider aspects such as aesthetics, ergonomics, trust or value for money. Product attachment implies the existence of an emotional connection between a person and an object. When someone becomes attached to an object, they are more likely to handle the object with care, repair it when it breaks down, and postpone its replacement as long as possible. So, fostering a strong product-user relationship can lead to lengthening the life span of many durable consumer products (Schifferstein & Zwartkruis-Pelgrim, 2008). The highest levels of attachment are registered for recently acquired products (<1 year) and for products owned for more than 20 years. However, attachment is determined by multiple themes, many of which are circumstantial to consumers' experiences and therefore difficult for designers to control (Page, 2014). So far, different studies reveal that for new products, enjoyment and pleasure may be the main driver of attachment, whereas for old products memories may be more important. Appearance and reliability also have considerable influence on participants' attitudes towards replacement. Designers should create products that are both useful and enjoyable. This asks for products that evoke sensory and aesthetic pleasure.

Proposed design criteria for long-life products are:

- Strong product-user relation;
- Durable and wear-resistant materials and components;
- Timeless and customized design;
- Reliability;
- Lifespan information to clients/consumers;
- User-friendliness/inclusive design.

Design for product-life extension

Product life extension is an increase in the utilization period of products, which results in a slowdown of the flow of materials through the economy (den Hollander & Bakker, 2012).

Designers can incorporate features that enable products to serve their originally planned functions over a longer period without losing their performance or that can be maintained or even, upgraded to extend their life and maintain the attractiveness throughout time to its user. The extension of life is the counterstrategy to the implanted programmed obsolescence, in which the products are designed to lose part or all of their performance after a specific time.

This strategy is complementary to the promotion of a set of services linked to the product that enables the technological and emotional extension of the function of the product. The design of the product must, from the initial stages of the process, foresee that an action by the user or expert services can be applied in the product or components, to reset or upgrade the function for which the product was designed.

For the effectiveness of the strategy, the design process must take into account simple solutions for disassembly/assembly and modularity/standardization, to promote easy maintenance and repair, upgrade, and reuse of the product or components (Bocken, 2016; Gerrittsen, 2015). Designers have several different methods available to them for designing adaptable products, with product architectures that provide robust support for adapting products to meet changes in functional and environmental requirements, as well as advances in technology (Levandowski et al, 2015; Zhang et al, 2015).

According to Stahel (1998, p.29), the key to extending product life "lies in transforming an industrial economy focused on the real linear output to a service economy focused on the use of loops." In the background, this is a concise perspective of the thinking that the design practice has to move towards a circular economy.

Design criteria for product life extension include:

- Easy replacement of components;
- Aesthetic and/or technical upgradeability;
- Durable and wear-resistant materials and components;
- Use of modular solutions;

– Simplified product architecture;
– Choice of tools needed for dis- and reassembly;
– Minimize connecting elements;
– Facilitate access and detection of connecting elements;
– Standard connection elements.

Design of product-oriented services

This strategy includes different types of services that prolong the lifetime of products. They concern consumer products as well as business-to-business situations. The business model is still mainly based on the sales of products, but some extra services are added (Tukker, 2004). For these services to be successful, products must be designed in such way that they are easy to disassemble, repair, maintain, refurbish, clean or upgrade. Often, these services are linked to the selling of consumables, spare parts, and add-ons to support the life cycle of long-lasting products (Achterberg et al. 2016). Since these services are additional to (and not replacing) the selling of products, the life cycle costs of the products are not retained by the provider, and thus the incentive to extend their lifetime at the maximum possible may not exist, unless if the client or consumer clearly rewards that or if the revenues related to repair or maintenance are significant. The sustainability potential of these services depends on the actual increase in the lifetime of the goods.

Services for a long life of products typically bring the following benefits:

– They are the most efficient way to retain or restore the system back to normal working conditions (Ajukumar & Gandhi, 2013);
– They are a source of competitive advantage and business opportunity (Armistead & Clarke 1992);
– They may generate more than three times the turnover of the original purchase (Wise & Baumgartner, 1999);
– They provide protection, pollution prevention, personnel safety and waste disposal (Ajukumar & Gandhi, 2013).

Examples of product-life extension services include:

– Maintenance, repair, refurbishment and cleaning services: e.g. repair cafes, services provided by the product manufacturing company (very common e.g. in the automotive and technology product firms, that in this way generate a fair percentage of their total revenues (Cusumano et al., 2008), services provided by retailers, services offered by specialized companies.

- Technological upgradeability: computers, telephone systems and copiers are examples of products prone to this type of services (Entrepreneur, n.d.) They can be offered by manufacturers, retailers and specialized companies.
- Aesthetic/cultural upgradeability: examples of this service can be found in the furniture, apparel and decorative objects industries, mostly offered by small workshops. In the construction industry, on the contrary, aesthetic upgradeability is a very big business and often part of larger renovation works. Examples can be found in Galgani (2014).
- Advice, consultancy and training concerning prolonging the lifetime of products. This can be offered by the product provider, by other companies or even by individuals, (a typical example are all the videos available on YouTube on "how to fix." or "how to repair." all kinds of appliances, cars, furniture, apparel, etc.).

Design criteria for product-oriented services:

- Geographic accessibility of services;
- Variety of service offers;
- Influence on product design;
- Customer satisfaction;
- Added value (for customers);
- Employment creation;
- Good working conditions;
- Transportation sustainability;
- Involvement and promotion of local community.

Design of use- or result-oriented services

In this strategy, the keyword is "ownership". The provider retains the ownership of the product and makes it accessible to the clients (again, individuals or organizations) through different business models (Tukker, 2004). For the description of use-oriented services, such as leasing, renting and sharing, pooling, and result-oriented services, see subsection 5.1.2. Here, the sustainability potential of the different types of services is discussed.

Leasing: In terms of sustainability, this kind of services may be interesting if the provider may influence the design of the product since it is his/her own interest that the product lasts a long time. If the provider cannot influence the product design, the potential benefit relates to more efficient use of energy or consumables by better maintenance, repair and control. This service has tangible value for the user since various costs and activities are shifted to the provider.

Renting and sharing: The sustainability potential can be high if the life cycle impacts are mainly related to manufacturing, as a smaller number of products may accomplish the needs of multiple users when compared to the traditional product ownership model. Renting and sharing may represent a significant effort by the user into getting access to the product, but the tangible benefit is related to not needing to bear the capital costs. Renting normally does not contribute to self-esteem or intangible experiences, except if the product-service combination is designed with that purpose (e.g., possibility to customize a rented car).

Pooling: The access to the product may put even more challenges to the users then renting or sharing, related to the simultaneous use. On the other hand, the intensity of use of products is even higher and the benefits in terms of environmental impact can be significant, especially if the life cycle impacts of the product are related to the use phase.

Result-oriented services: Like in the above types, the ownership of products is not transferred to the client; since all life cycle costs stay with the provider, they will try to find innovative ways to reduce costs and liabilities and has more room for manoeuvre to design a low impact system with high customer satisfaction. Examples of this strategy are the "pay per lux" service offered by Philips at Schiphol Airport, the "power by the hour" of service of Rolls-Royce engines in Boeing aircraft or Nor- Line vessels, or the "pay per mile driven" service (tires), by Michelin. Taking this last example: customers pay per miles driven; they don't own the tire and don't have to worry about maintenance are any problems that occur with the tires. On the other hand, Michelin has an incentive to design long-lasting tires and, by taking back worn-out tires, the company is motivated to design them so that they can be reprocessed into a valuable input for new tires or another product (Accenture, 2014).

Information and communication technologies (ICT's) have a very important role as enablers and facilitators of 'products as services' as they allow for establishing real-time information exchanges among users, machines and management systems. Examples of application are apps for sharing and pooling platforms, materials tracking in the built environment, etc.

The more intense the use of 'products as services' is, the more their potential to contribute to a CE is unlocked. Therefore, they should be easily accessible, add value to the customers and be designed and operated to achieve a high level of customers' satisfaction. Other considerations to render higher levels of sustainability relate to transportation and involvement of local communities.

Design criteria for use- and result-oriented services:

- Accessibility;
- Influence in product design;
- Impact of the service in resources use intensity;
- Existence of easy and affordable information and communication technologies;
- Customer satisfaction;
- Added value (for customers);
- Transportation sustainability;
- Involvement and promotion of local community;
- Employment creation;
- Good working conditions.

4.3.1.1 Strategies for closing resource loops

Design for remanufacturing

Through remanufacturing, a used product returns to a "like-new condition"; it is a process of recapturing the value of the material when a product was first manufactured. Remanufacturing results in the reduction of energy and material consumption, and of production costs (Gray & Charter, 2007), allowing the manufacturer to increase the productivity as well as the profitability in the business (Fegade et al., 2015).

Remanufacture can offer a business model for sustainable prosperity, with reputed double profit margins alongside a significant reduction in carbon emissions and the energy required in manufacture.

The potential or remanufacture is affected by the physical characteristics specified during the design phase, like the complexity and modularity of the products, the possibility to maintain or adapt technologies, the quality and durability of the materials and the solutions adopted in the product, etc. Design for Remanufacture is enabled by business models which recognise the benefits of remanufacturing and services like reverse logistics which allow that the products return to the factory at an affordable cost.

Remanufacture views end-of-life products and components as a resource. Promotion of remanufacturing can, therefore, benefit both the economy and the environment. Design for Remanufacture can optimise the process of remanufacturing, increase the practice of remanufacturing and therefore increase the significant economic development opportunities for businesses and people.

This strategy also avoids that valuable material materials and components ends low valued valorisation or in a landfill and creates a market for skilled employment and, in principle, is preferable to recycling. The value of materials and components is maintained by returning products to working order, whereas recycling simply reduces the used product to its raw material value (Ijomah et al., 2007).

Although in theory any product can be remanufactured, the business case, which would make remanufacture economically feasible, varies between sectors and products, and the integration of other considerations like design for disassembly, which enables the process. Design for remanufacturing optimizes remanufacture through consideration of both the business model and the detailed product design and must be considered in the initial design of the product (Gray & Charter, 2007).

Design criteria for remanufacturing:

- Technology integration/stable technologies over the lifetime;
- Use of modular solutions;
- Existence of a take-back system;
- Optimize reverse logistics (RL) network and involve the supply chain in RL planning;
- Durable and wear-resistant materials and components;
- Simplified product architecture;
- Minimize connecting elements;
- Facilitate access and detection of connecting elements;
- Standard connection elements;
- Employment creation;
- Good working conditions.

Design for recycling

The objective of this strategy is to develop products in such a way that the materials ("technical nutrients") can be continuously and safely recycled into new materials and products (Bocken et al., 2016). Although in many cases recycling is one of the last strategies to consider in the development of products and services within circular economy, design for recycling is a strategy to be considered by design teams. Designers must understand the process and the conditions for efficient and quality recycling, resulting in quality materials that can be used as valuable input material in the product or service cycle. The potential of recyclability of a product can be enhanced by the easiness to disassemble the product.

Recycling is the process of recovering materials for the original purpose or other purposes, excluding energy recover. To establish a continuous flow of resources in the technological cycle, the "waste" resources are to be recycled into materials having properties equivalent (or even superior, in a process, called upcycling) to those of the original material (Bocken at al., 2016). In the majority of nowadays recycling operations, what occurs is downcycling (reprocessing into products requiring lower properties), which does not enable a circular flow of resources, but only delays the linear flow of resources from production to waste (McDonough & Braungart, 2002).

Design for recycling aims at designing products which materials that can be recycled without property losses (and therefore endlessly, in theory). As for the use of recycled materials in the product, that is part of the quality of input materials and is addressed in the 'Design for materials sustainability' strategy.

Design criteria for this strategy:

- Choice and variety of materials for easy recycling;
- Marking of materials for recycling;
- Easy separation of technological from biological materials;
- Minimize connecting elements;
- Facilitate access and detection of connecting elements;
- Standard connection elements;
- Avoid the use of dangerous tools and processes;
- Employment creation;
- Good working conditions.

4.3.1.1 Strategies for narrowing resource loops

Design for materials sustainability

The selection of materials, (including water and components) and the quantity of material used, are key elements in the definition of the potential impact of a product or a service. In the design phase, the design teams can choose materials and components with lower impact by itself, or that have a positive influence on the product or service systems and can adopt measures to reduce the number of materials used by implementing efficiency strategies in the design. Decisions taken in the conceptual design phase are fundamental to influence the efficiency and optimization of material consumption in the life cycle of the product or service.

It is difficult to fully describe what a sustainable material is. It depends not only on the materials but the conditions in which it is transformed, applied and used. However, we can affirm that sustainable materials are ones that have a lower embodied energy as well as a lack of emissions, waste and making sure that the material continues to be created or grown rather than deplete its stocks.

Another way to describe them can be by looking at them as the materials whose use achieves environmental benefits, unlike other conventional materials.

Apart from the reduction of resource consumption, other strategies, influencing the efficiency in the life cycle can be adopted. Optimizing resource cascading can be an option to prolong the lifecycle of resources.

Resource cascading is the sequential exploitation of the full potential of a resource to improve resource efficiency. Resource cascading allows for significantly extending a resource's useful life through repeated utilization. This approach to production and consumption states that energy recovery should be the last option, and only after all higher-value products and services have been exhausted. This concept is often associated with the forestry sector, in which cascading use can be effectively demonstrated.

Several sustainability issues must be considered in the selection of input materials and components that constitute the product or that are necessary to provide the product-service. Are the materials hazardous, non-renewable or scarce? Are they virgin or recycled? Can they be recycled? Do suppliers have good environmental and social practices? Are the materials and components local, or do they have to travel long distances and do not support the local or regional communities' economies?

Based on the materials and components used in the product or product-service and the processes necessary to manufacture them, the possibility of using alternative ones with better environmental, social and economic performance must be analysed.

Designers who can develop solutions to fulfil the needs of the users using less and more sustainable resources (materials and water), have a higher potential to succeed in the creation of more circular and sustainable solutions.

Design criteria related to this strategy:

- Optimize products' design (shape, size, weight, etc.) to reduce material consumption;
- Avoid consumable components and materials in the use phase;
- Use of recycled materials;
- Eliminate the use of toxic materials in the product;
- Promote the use of renewable materials in the product;
- Use of locally produced raw materials and components;
- Avoid the use of scarce and/or critical materials;
- Use of raw materials and components from suppliers with good social responsibility practices;
- Information on product sustainability to consumers;
- Influence sustainable consumer behaviour regarding consumables in the use phase.

Design for energy sustainability

Like in other areas, product design should take into account the energy that the product will need to meet user needs, taking the whole life cycle into account. For energy-using products (e.g. electronics, cars, lighting), the use phase may be the most important one; however, for many other non-energy consuming products (such as furniture or packaging), the manufacturing phase can represent a significant portion of energy consumption.

Another emerging area is related to technologies in the field of renewable energy, such as small fuel cells, flexible photovoltaic solar cells and human power. As renewable energy sources develop and become smaller and more flexible, possibilities of integrating them into the product design have emerged. However, until recently, renewable energy technologies have been more or less "pasted" upon the products instead of being integrated into the design of the product. It is a big challenge to find the appropriate products or functions for these new technologies and to integrate them into the total design of the product (Mestre & Diehl, 2005).

This strategy thus encompasses energy efficiency in the various stages of the life cycle through design options, the use of solutions that incorporate renewable energy and influencing consumer behaviour regarding energy consumption.

Related design criteria are:

- Reduce energy consumption in production;
- Reduce energy consumption in use;

- Reduce energy consumption in transport;
- Energy plus;
- Replace non-renewable by renewable energy;
- Use low embodied energy materials;
- Information on energy consumption to clients/consumers;
- Influence consumer behaviour regarding energy consumption.

4.4 Examples of application of the strategies

Unlike the other chapters in the present research, this chapter has a very practical approach, as it was developed in the context of a project that targeted a very direct application of results to companies.

The original chapter of the book in which it was written included examples of products that are in accordance with the strategies here proposed and illustrate their applicability in real life contexts. Some of these examples are presented in Annex 1 of this thesis.

5

DESIGN FOR CIRCULAR ECONOMY IN A STRONG SUSTAINABILITY PARADIGM[5]

Abstract

Given the strategic role of design when addressing societal changes and its prominence in the circular economy (CE) discourse and practice during the past decade, a plethora of tools and methods is nowadays available to support organizations in the transition from a linear model of production to a circular one. The need for an intersection of CE, corporate sustainability, strategic design and strong sustainability is gaining momentum. Considering (a) the critical voices pointing out several limitations to the CE concept, (b) the call for linking CE to a strong sustainability paradigm as well as (c) the implementation mechanisms for an effective contribution to sustainable development, the focus of this research is to address the gap in CE and circular design frameworks due to missing elements therein for its successful implementation, using a Delphi method approach. Our results strongly suggest that the current circular economy and the circular design concepts and practices are insufficient to meet the challenge of addressing strong sustainability and new models are needed. To conclude, a new definition of design for CE in a strong sustainability paradigm, and a first approach to the main elements of the improved model assisted by guiding principles are proposed.

Keywords: circular economy, circular design, strong sustainability, implementation model, principles.

---

[5] *Published as a peer-reviewed article:*
Rocha, C.S.; Antunes, P.; Partidário, P. Design for Circular Economy in a Strong Sustainability Paradigm. Sustainability 2023, 15, 16866. [*https://doi.org/10.3390/su152416866*](https://doi.org/10.3390/su152416866)

5.1 Introduction

In March 2022, the European Commission presented a package of proposals within the European Green Deal, (European Commission, 2019), to make sustainable products the norm, advance circular business models and empower consumers for the green transition (European Commission, 2022). The proposal establishes a framework to set ecodesign requirements for specific product groups to significantly improve their circularity, energy performance and other environmental sustainability aspects. It follows the second Circular Economy Action Plan (European Commission, 2020), which calls for "a regenerative growth model that gives back to the planet more than it takes, (…) keeping resource consumption within planetary boundaries" (European Commission, 2020, p.2). The circular economy (CE) is considered as the economic model that can make a decisive contribution to achieving climate neutrality by 2050 and decoupling economic growth from resource use, while ensuring competitiveness and equity in the European Union.

Although loosely defined (Calisto Friant et al., 2020; Geissdoerfer, Savaget, Bocken, et al., 2017; Ghisellini et al., 2016; Kirchherr et al., 2017; Korhonen, Honkasalo, et al., 2018), CE is an umbrella concept (Merli et al., 2018) advocated as a strategy to achieve sustainable development (see, for instance, Nikolaou & Tsagarakis (2021). In the words of Sauvé et al. (2016), it gives "a clear angle of attack to help solving environmental problems" (p. 55) by acknowledging that in a materially closed system such is the Earth, a linear use of resources ("take-make-dispose"), even if directed by efficiency objectives (doing more with less), is unsustainable. In a linear economic system, the depletion of resources (particularly the non-renewable ones) and the generation of waste and emissions will always occur, and environmental management strategies like eco-efficiency, cleaner production and ecodesign fail to address that, since most of them focus on "less bad" products (Moreno et al., 2016) and processes, rather than in "transforming products and their associated material flows such that they form a supportive relationship with ecological systems" (Ellen MacArthur Foundation, 2012a). In a CE, material flows are made up either of biological materials, which after discard are available for natural cycles in the biosphere, or of materials designed to circulate within the technosphere (Ellen MacArthur Foundation, 2012b; UNEP, 2012).

For organizations, the CE is a systemic approach to the design of processes, products/services and business models, enabling sustainable economic growth by managing resources more effectively as a result of making the flow of products and materials more circular and reducing and ultimately eliminating waste (adapted from British Standards Institute, 2017). In a CE, companies need to deliver products, which are intrinsically more durable and that can be reused, repaired, refurbished, remanufactured and recycled (Bocken et al. 2016). It also asks for offering services that provide the same or improved functionality in a more dematerialized way (Stahel, 2010). Since it is at the design stage that these features are mostly defined (Andrews, 2015; Moreno et al., 2016), circular design has become important in the CE debate.

The adoption of circular design by companies can be considered as part of corporate sustainability, defined as "an integrated, systemic approach by business that builds, rather than erodes or destroys, economic, social, human and natural capital" (Visser, 2011, p.1). This definition places emphasis on businesses operating in a way that benefits the different types of capital, rather than reducing the harm they do. This idea is also being advocated by proponents of the CE, as mentioned above. Many authors have noted that corporate sustainability, despite being adopted by an increasing number of companies, has not produced the desired effect in terms of sustainable development (Dyllick & Muff, 2016; Landrum, 2018; Visser, 2012), since the environment continues to decline while millions of people still fall short in social minimum standards, as identified, for instance, within the UN Sustainable Development Goals (Raworth, 2017).

The disconnect between the increasing number of companies claiming to adopt sustainability practices and the continuous degradation in the environment (also noted by Visser, 2012) may be explained by the fact that corporate sustainability developmental models are framed around a weak sustainability perspective (Landrum, 2018). Several authors argue for the need to align corporate sustainability (Bjørn & Røpke, 2018; Nikolaou et al., 2019), design for sustainability (Gaziulosoy, 2013) and business model innovation (Brozovic, 2020), with strong sustainability. However, it is arguable that companies adopting CE principles are inherently aligned with strong sustainability, as the debate around the intersection between these concepts is open (Lefstad, 2021; Martins, 2016; Schröder et al., 2019).

Moreover, existing strategies to implementing CE in organizations and value chains are more developed in identifying opportunities and designing new business model concepts, and lack methods and tools for experimenting, testing, and implementing them (Lindgreen et al., 2020; Mendoza et al., 2017; Pieroni et al., 2019).

This paper aims at dealing with a complex problem arising from several findings from literature and practice that are further explained in section 5.2:

- The CE is expected to deliver an important contribution to sustainable development by decoupling economic growth from the environmental degradation and resource exhaustion, but it has limitations, e. g. increase in transport related to reverse logistics, energy inefficiencies related to prolonging the lifetime of some products, energy-intensive recycling processes, etc.; sufficiency is advocated as required to complement efficiency and circularity in a truly sustainable system, in which growth is in itself arguable.
- Corporate sustainability management has also fallen short in contributing to sustainable development and t most corporate management systems and practices are framed around a weak sustainability perspective. Once CE (and particularly circular design) is embedded in corporate sustainability frameworks, there is a need to ensure that it follows a strong sustainability perspective.
- There is still a gap in CE and circular design frameworks, as they do not include the necessary elements to a successful implementation, let alone in a perspective of strong sustainability.

This research aims at contributing to fill this gap in models that support design for CE in a strong sustainability paradigm, by addressing the following research questions[6]:

RQ 1: How can design for a CE in a strong sustainability paradigm be defined?

RQ 2: How do CE and strong sustainability relate to each other?

Sub question 2a: Which are the features of CE and strong sustainability that are aligned?

Sub question 2b: Which are the features of CE and strong sustainability that are conflicting?

RQ 3: Which is the added value of a model that supports companies in the design for a CE in a strong sustainability paradigm?

RQ 4: Which are the most important elements of a model of design for a CE in a strong sustainability paradigm?

[6] The numbering of the research questions here presented differs from the one found in section 1.2, as they were renumbered to fit the overall project. Thus, RQ's 1-4 in this chapter correspond to RQ's 1.3-1.6 in section 1.2.

This article builds upon previous research, which has shown that several sustainable design supportive models have been developed targeting products, product-service systems and societal developments and that they share common features involving action and decision making at the strategic, tactical and operational levels, as detailed in section 5.3. Positioned at the intersection of CE, corporate sustainability management, strategic design and strong sustainability at micro level, it intends to respond to calls for research (e.g, Bocken et al., 2016; Geissdoerfer, Savaget, & Evans, 2017; Schaltegger et al., 2016) by proposing an implementation model of design for CE in a strong sustainability paradigm, with the following assumptions:

I. It is meant to support companies in product, product-service system and business model design for CE and sustainability with a systemic view;
II. The concept of CE is considered from the perspective of sustainable development and its three concentric, hierarchical dimensions: environmental, social and economic (Korhonen, Honkasalo, et al., 2018; Lozano, 2008);
III. It is aligned with corporate sustainability strategies placed in the strong to very strong side in the sustainability spectrum (Landrum, 2018);
IV. It encompasses the perspectives of academics and practitioners.

5.2 Theoretical background

5.2.1 CE and circular design: concepts and limitations

The CE offers a fundamental alternative to the still predominating linear take-make-consume-dispose economic model. The linear model assumes that natural resources are available, abundant, easy to source and cheap to dispose of, but there is undeniable evidence of the unsustainability of this way of producing and consuming. On the other hand, the CE is a resource-based (Desing et al., 2020b) operational concept to reconfigure the currently linear system into circular and regenerative socio-economic models.

A CE requires the implementation of three basic principles, driven by design (Ellen MacArthur Foundation, 2015):

1. Preserve and enhance natural capital by controlling finite stock and balancing renewable resource flows.
2. Optimise resource yields by circulating products components and materials in use at the highest utility at all times in both technical and biological cycles.

3. Foster system effectiveness by revealing and designing out negative externalities.

Different disciplines (such as ecology, economy, engineering, design and business) have contributed to the development of the CE concept (Prieto-Sandoval et al., 2018), resulting in different foci and definitions. Kirchherr et al. (2017) analysed nothing less than a sample of 114 definitions and proposed their own definition, which reads (p. 229):

"(CE is) an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers."

This definition was presented as an effort to provide a conceptual foundation for future work on CE (Kirchherr et al., 2017). Taking it, as well as definitions later published in the literature (Alhawari et al., 2021; de Jesus et al., 2019; Desing et al., 2020b; Geisendorf & Pietrulla, 2018; Korhonen et al., 2018; Nobre & Tavares, 2021; Prieto-Sandoval et al., 2018; Schmidt et al., 2020), an analysis of overarching objectives, CE strategies, identification of enablers and indication of different scales to which CE applies (appendix A) was performed, revealing the diversity of understandings behind this concept. Most of the analysed definitions place CE in terms of contribution to sustainability (mostly environmental sustainability) and include CE strategies and enabling factors (i.e., indicating not only what CE is, but also how to achieve it). The most comprehensive framework of CE strategies is proposed by Potting et al., (2017), the so-called 9Rs, including R0 (refuse), R1 (rethink), R2 (reduce), R3 (reuse), R4 (repair), R5 (refurbish), R6 (remanufacture), R7 (repurpose), R8 (recycle) and R9 (recover), in which the highest circularity corresponds to R0 (make the product redundant by abandoning its function or by offering the same function with a radically different product) and the lowest corresponds to R9. In this framework, recycling (i.e., processing materials to obtain the same or lower quality) is close to a linear economy.

Given the limited conceptual grounding of CE (Velenturf & Purnell, 2021), there are different views on the relationship between CE and sustainability. While some authors argue that CE is a precondition to sustainable development, since resource use and waste are reduced, others point out that such vision is simplistic and disregards trade-offs that always occur (Iacovidou et al., 2021) and the social dimension of sustainability (Murray et al., 2017). In an extensive literature review, Geissdoerfer, Savaget, Bocken, et al. (2017) reported views according to which CE is seen as the main solution for a transformation to a sustainable system or at least a necessary, even if not sufficient, condition for sustainability. On the other hand, the same study concluded that CE can also lead to negative outcomes related to the technical unfeasibility and the required energy of a closed circle.

When reflecting on the weak relation between CE and sustainable development, Velenturf & Purnell (2021) point out that for instance industrial symbioses may be sustainable, but (1) they can also lead to locking-in unsustainable material systems, such as the network of petrochemical industry infrastructure, (2) the exploitation of the decarbonisation potential of CE requires system thinking to avoid shifting emissions from one system to another and (3) a larger use of biological materials to substitute mineral resources can demand water resources beyond sustainable levels of supply.

The CE is seen as an instrument to decouple economic growth from environmental impacts and depletion of resources (Ellen MacArthur Foundation, 2015). The need of decoupling has been pointed by scientists and policy makers for many years (Fischer-Kowalski et al., 2011; Giljum et al., 2005; Jackson, 2009; Meadows et al., 1972; von Weizsacker et al., 1998; Weizsäcker et al., 2014), although several authors point out the need to complement efficiency with sufficiency (Parrique et al., 2019). According to Calisto Friant et al. (2020, p.2), "The question of growth is perhaps the largest elephant in the room for the CE". This is at odds with the view that a CE leads to a desired growth that comes from "within", by capturing the value in existing economic structures, products, and materials, as advocated by the Ellen MacArthur Foundation (Ellen Macarthur Foundation; McKinsey & Company, 2015). This is contested because indefinite recycling and reuse of resources is not possible and there is no evidence that CE could lead to absolute decoupling of economic growth from environmental degradation (Antikainen et al., 2018, as quoted by Calisto Friant et al., 2020).

5.2.2 Circular design strategies

CE represents a new way of understanding value in the economic system, in which companies deliver products whose value can be maximized over time, which are intrinsically more durable and can be reused, repaired, refurbished and remanufactured, and whose materials can be recycled (Bocken et al., 2016).

It is at the design stage that these features can be mostly defined (Andrews, 2015; Moreno et al., 2016). Designers can create products that are built to last because of their robustness or by creating a symbolic attachment with the user; they can develop modular and standardized products that can be reconfigured to fulfil different functions; they can also design for dis- and reassembly, thus facilitating repair and refurbishment (den Hollander et al., 2017; Sumter et al., 2017). Indeed, circular design has become very important in the CE development, not only at the product level, but also at the business model (BM) level (Chesbrough, 2010; Boons & Lüdeke-Freund, 2013; OECD, 2019). Moreover, acknowledging the fact that research in the fields of design and sustainable development have crossed their paths in addressing societal challenges (Ceschin & Gaziulusoy, 2016; Joore & Brezet, 2015), Baldassarre et al. (2019) suggest that the strategic role of design for sustainable development has been evolving from product design, to product-service systems design, to BM design, to ecosystems design. All these scopes are relevant for positioning the CE as a systemic transformation and this research is concerned with the role of design in supporting such transformation.

Like what happens with the concept of CE, there is no agreed definition of design for a CE, especially when embracing the different scopes, ranging from product to ecosystem design. Most of existing definitions focus on circular product design (den Hollander et al., 2017; Moreno et al., 2016; van den Berg & Bakker, 2015).Schmidt et al. (2020), however, propose a comprehensive definition (p. 31): *"Design for Circular Economy is the design and development of products, services and product-service systems that replaces the conventional end-of-life concept by closing, slowing and narrowing the resource flows in production, distribution and consumption processes. It is enabled by innovation and novel business and organizational models and aims to accomplish sustainable development through supporting of ecosystem functioning and human well-being, and through responsible production and consumption."*

The systematization of circular design strategies proposed by several authors (e.g., Bocken et al., 2016; Geissdoerfer et al., 2016; Konietzko et al., 2020; Rocha et al., 2020) (appendix B) misses the social dimension of this definition; on the other hand, the regeneration of resource loops and the use of information technology as a support strategy (in addition to closing, slowing and narrowing) is included in the work of Konietzko et al. (2020). Appendix B shows that there are remarkable differences in the degree of development of circular design strategies: the work in this area is more mature for products and business models than for ecosystems; on the other hand, strategies related to closing, slowing and narrowing resource flows are more developed than those related to regeneration of resource flows, which need to be taken into account from a strong sustainability perspective.

5.2.3 Existing frameworks to support companies in the transition towards CE

There is a wealth of publications on methodologies and tools to support CE transition, focusing on business models, assessment and metrics, product design and the creation of organisational capabilities such as experimentation, value chain innovation and other human factors (Blomsma et al., 2019; Lindgreen et al., 2020). For our work, the frameworks of interest are those that support the process of transforming products, services and business models into more circular ones. In Appendix C, examples are presented, illustrating different perspectives that exist and, at the same time, uncovering gaps to be filled in by research.

These frameworks are highly diverse, in terms required effort from companies (from short sessions to complete management systems), activities (from assessment to visioning to full implementation of CE transitioning processes) and focus (products, business models or ecosystem design and innovation, as well as organizational management aligned with CE). They tend to coincide in the adoption of a systemic, multistakeholder approach and in addressing the environmental, social and economic dimensions of sustainability. However, none of these frameworks was developed with the explicit concern of aligning CE with a strong sustainability view which, in our view, is critical to a meaningful contribution to sustainable development, as explained in the following section.

5.2.4 A call to link CE and circular design to strong sustainability in corporate sustainability management

Dyllick & Muff (2016) note that, although there is an increase in the adoption of sustainability practices by companies, paradoxically the environmental degradation worsens. Landrum (2018) built on their work and proposed a new unified model of corporate sustainability stages that draws heavily from ecological economics science. It was used to analyse 22 corporate sustainability, corporate social responsibility, environmental management and sustainable development models at micro-level, concluding that these are framed around weak sustainability, as opposed to strong sustainability and, according to Landrum (2018), this provides an explanation to the above-mentioned paradox. The key idea in weak sustainability is that natural capital and other types of capital (e.g., manufactured) are interchangeable, whereas in strong sustainability the substitutability of natural capital is severely limited (Mancebo, 2010; Pelenc et al., 2015).

The unified model proposed by Landrum (2018) is organized in five stages in the sustainability spectrum at firms' level, ranging from very weak sustainability to very strong sustainability:

- **Stage 1 (very weak sustainability)**: Compliance, firms are defensive and react to external demands, such as regulation.
- **Stage 2 (weak sustainability)**: Business-centred, firms adopt sustainability initiatives for the business-case, exploit nature for industrial gain, are technocentric; this stage is growth- and consumption-oriented; sustainability is understood to mean "less bad".
- **Stage 3 (intermediate sustainability)**: Systemic, adopts an environmental, economic and social perspective of sustainability; views businesses as part of a larger industry and community and pursues systemic change, but continues to seek increased growth, production and consumption; sustainability is understood as to do "more good".
- **Stage 4 (strong sustainability)**: Regenerative, looks beyond growth and consumption, seeks no increase in scale, integrates environmental and ecological science, and acknowledges limits. It seeks to repair the damage of the industrial consumer economy with activities such as restoring and regenerating nature, reconciliation of species, repair of the commons and creating diversity.
- **Stage 5 (very strong sustainability)**: Coevolutionary, adopts a view of "participating" cooperatively in the symbiosis and self-management of consumption and use of resources. For businesses, it means to adopt an ecological science-based view in which there are planetary boundaries, a view of interdependency and the pursuit of a steady-state with limited or no quantitative growth. Business becomes a fertilizer for life. Landrum did not find any micro-level model that corresponds to this stage but states that it is critical to addressing the paradox.

Given the objectives of the present research, it is worthy to reflect on the positioning of CE principles and practices across the sustainability spectrum, considering the understanding and frameworks presented in sections 5.2.2 and 5.2.3. This is presented in table 5-1, indicating that there is a closer alignment with features of the systemic stage (intermediate sustainability).

Table 5-1: Characteristics of the CE when compared to Landrum's (2018) unified model of stages of corporate sustainability.

	Descriptors of the stages of corporate sustainability (Landrum, 2018)				
	Orientation	**Understanding of sustainability**	**Relationship to natural world**	**Economic growth**	**Sustainability concerns**
CE features (own evaluation following Landrum' (2018) description)	Economic science, business oriented.	"Do more good" Business is part of a larger industry and community working together toward systemic change.	Part of the natural world, operate within planetary boundaries, manage and repair.	Pursuit of production, consumption and growth.	May focus on one or more realms of sustainability (economic, environmental, social), rather than the three of them.
Classification (highest level according to Landrum's (2018) description)	Systemic (intermediate sustainability)	Systemic (intermediate sustainability)	Regenerative (strong sustainability)	Systemic (intermediate sustainability)	Business-centred (weak sustainability)

Given the multitude of CE discourses (Calisto Friant et al., 2020), for this analysis we took the most "advanced" views of CE as displayed in Appendix A. We can conclude that CE is better positioned in the sustainability spectrum than the models analysed by Landrum (2018) (something that the author acknowledges, p. 303), although in our analysis it does not fulfil all the requirements of strong (let alone very strong) sustainability stages. A. Idil Gaziulusoy et al. (2013) concur, as they state that even if CE shares principles with strong sustainability, the latter is not evident in the existing CE frameworks; it needs to be clear that businesses are subject to the irreversible, hierarchical relationships between the environment, society and economy of the strong sustainability model.

5.3 Research method and design of interactive forecasting

5.3.1 The Delphi method

The Delphi method is a systematic, interactive forecasting tool defined as "… a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone & Turoff, 2002, p.3). Through a programme of sequential individual questionnaires (rounds) intermixed with information and feedback derived from the previous phases (Brown, 1968), the same experts assess the same matters towards collective build-up of informed conclusions (de Jesus et al., 2019). It is well suited to the present research, given its complexity and transdisciplinary character.

The method has four characteristic features: (i) anonymity, (ii) iteration with controlled feedback, (iii) statistical group response, and (iv) expert input (Dufresne, 2017).

The limitations of the method include the fact that it aggregates subjective input, lacks a conventionally agreed design and can raise concerns as for the choice of experts, questionnaires building and consensus nudging (de Jesus et al., 2019). In the following subsections the methodological choices to address such limitations are presented.

5.3.2 Panel composition

According to Avella (2016), there is no standard when it comes to the size of the panel of experts, but panels typically fall between 10 and 100 experts and consist of either two or three expert groups, depending on stakeholders' interest on the subject of the research. In this case, the experts were required to have a diverse background and a good understanding of CE and (strong) sustainability at organizations level. The criteria for selecting the members of the panel are presented in table 5-2.

Table 5-2: Identification of experts for the panel

Types of stakeholders	Criteria for identifying panel members
Academia	- Identified in CE, circular design and/or (strong) sustainability literature. - Participants in scholarly events on the above-mentioned subjects. - Snowball identification.
Business, NGO's and public administration	- Participants in workshops on CE, circular design and/or sustainability, including those organized within the KATCH_e project[7]. - Snowball identification.

5.3.3 Delphi design

The Delphi method normally follows four distinct phases (Linstone & Turoff, 2002):

1. Exploration of the subject, wherein each expert contributes with additional information they find pertinent to the issue.
2. Reaching an understanding of how the group views the issue.
3. If there is significant disagreement, explore that disagreement to bring out the underlying reasons for the differences and evaluate them, if possible.
4. A final evaluation when all previously gathered information has been analysed and the evaluations have been fed back for consideration.

Figure 5-1 displays the Delphi process used in the research.

[7] KATCH_e: Knowledge Alliance on Product-Service Development towards Circular Economy and Sustainability in Higher Education (project nº 575793-EPP-1-2016-1-PT-EPPKA2-KA). (www.katche.eu).

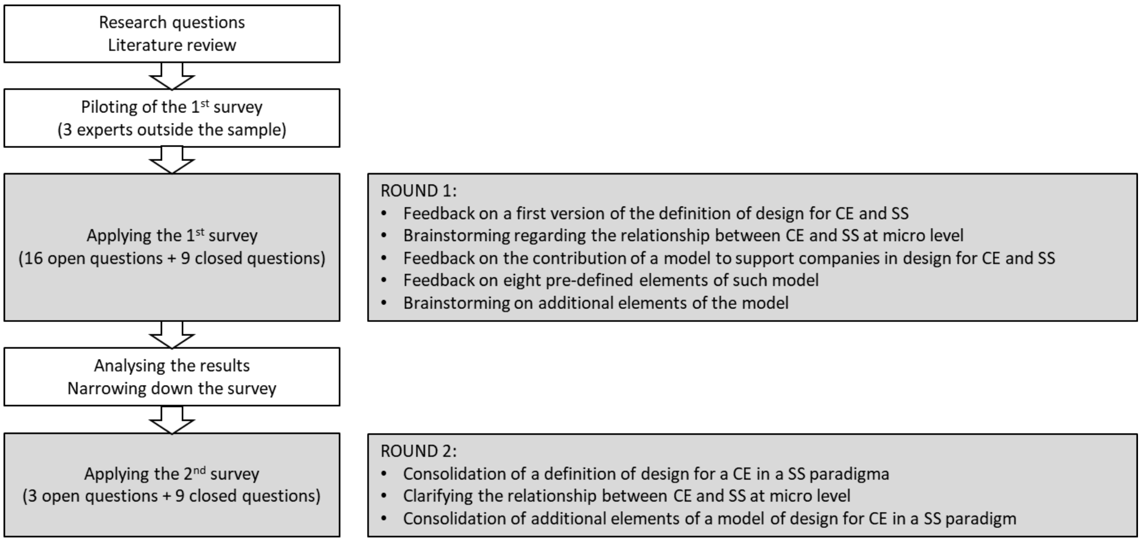


Figure 5-1: Overview of the Delphi process used in the present research.

Before the first round, a literature review in the subjects pertinent to the research questions was conducted (section 5.2). Then the first round was defined (table 5-3), and the first survey was tested by three experts outside the panel.

Table 5-3: Organization of the Delphi questionnaire (1st round) and justification.

Part	Justification
1. Definition of design for circular economy and strong sustainability (version 1)	Attempt to capture the relationship between design, circular economy and strong sustainability in a definition that can provide a sound framework for the model (RQ 1).
2. Circular economy and strong sustainability	Identification of features that are aligned and conflicting between the two concepts (RQ 2), given the lack of consensus in the literature regarding the contribution of circular economy to sustainable development, especially from a strong sustainability point of view.
3. Contributions of the model	Understanding the added value of a model that supports companies in the design for a CE in a strong sustainability paradigm (RQ 3), given the existence of circular economy and circular design frameworks, as well as design for sustainability frameworks (Rocha et al., 2019).
4. Elements of the model	The aim was to gather the experts' views on the relevance of a preselected set of elements that are present on most design for sustainability models (Rocha et al., 2019) in the context of circular economy and strong sustainability. Such elements were organized in three levels: strategic, tactical and operational. In addition, the experts were given the opportunity of identifying any missing element, at the three levels (RQ 4).

In the first round, the following definition of *design for the CE and strong sustainability* was presented to the experts (adapted from Schmidt et al., 2020), which was the basis for the first part of the questionnaire:

> *Design of products, product-service systems and business models that create positive, environmental, social and economic value and contribute to a society operating within the planetary boundaries, while promoting social well-being and equity.*
>
> *This is accomplished through closing, narrowing, slowing and regenerating resource flows in production, distribution and consumption processes, extracting the highest value and usefulness of materials, equipment and goods for the longest possible time, in cycles energised by renewable or otherwise sustainable energy sources, with a systemic view.*

As for part 4 of the questionnaire, it consists of the eight elements of design for sustainability models that resulted from the literature review undertaken by Rocha et al. (2019), presented in figure 5-2.

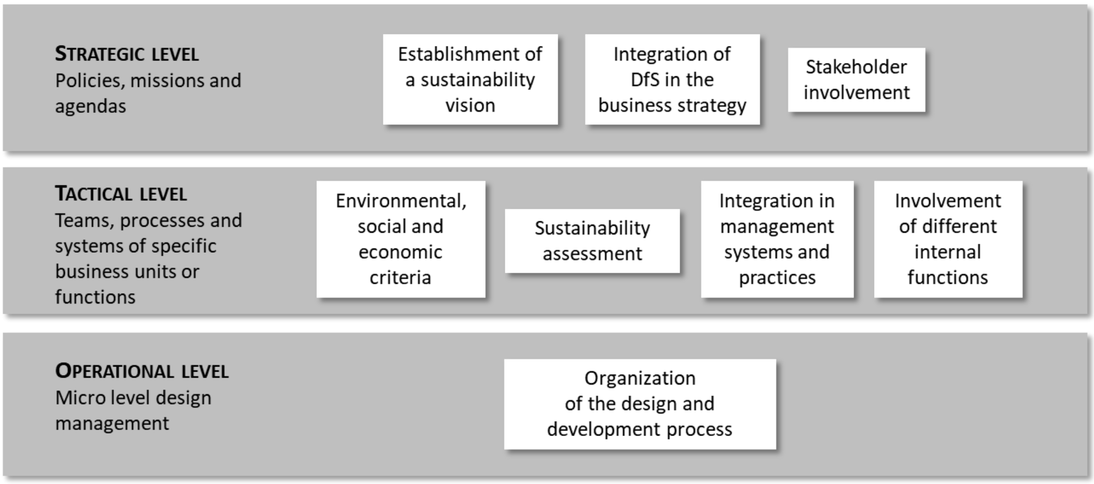


Figure 5-2: Analytical framework applied to DfS models (adapted from Rocha et al., 2019).

After the analysis of the first round's responses (which provided an overview of experts' opinions on the main subjects), a second questionnaire was developed, checking back and ranking findings. Only two rounds were considered necessary (the recommended number is two or three, according to Boulkedid et al., 2011), as it was assumed that further rounds would not enhance the results and could have fatigued participants and cause them to withdraw. The questionnaires of rounds 1 and 2 are available in Appendices D and E, respectively.

5.3.4 Data collection and analysis

The questionnaires were developed and answered using the free version of the *SurveyHero*[8] software. The statistical analysis of the quantitative answers included the calculation of mean, median, standard deviation, inter-quartile range (IQR), and Kendall's W. This research is focused on gathering knowledge and reaching consensus, and therefore the following assessment metrics were used to ascertain consensus (de Jesus et al., 2019):

- Over 50% agreement within two categories on a five-point Likert scale.
- Mean item ranking, share (%) of experts placing an item in the top half of their list, and Kendall's W (see table 5-4).
- Measures to quantify the amount of variation of dispersion. De Jesus et al. (2019) noted that different authors recommend different analysis and thus used the mean, the median, the IQR and the standard deviation in their work; such procedure was replicated here. A low standard deviation of 1.64 is proposed by some authors, whereas others consider 1.5. An IQR of around 1 indicates agreement and larger values indicate less agreement.

Table 5-4: Kendall's concordance degree scale (Moslem et al., 2019)

W	Interpretation
0	No agreement
0.10	Weak agreement
0.30	Moderate agreement
0.60	Strong agreement
1	Perfect agreement

[8] www.surveyhero.com

5.4 Research method and design of interactive forecasting

5.4.1 Description of the sample

Of the 44 questionnaires sent, 17 were completely answered in the first round, which corresponds to a 39% response rate, in line with typical value of 40% (Gordon, 1994); 15 experts within this group answered the questionnaire of the second round.

One of the advantages of Delphi is that there are no limits to the geographic coverage. In this case, it was only possible to get answers from Europe and North America (with a total of seven countries, figure 5-3), although invitations were sent to experts from Brazil, China, South Africa and Australia, seeking a broader coverage.

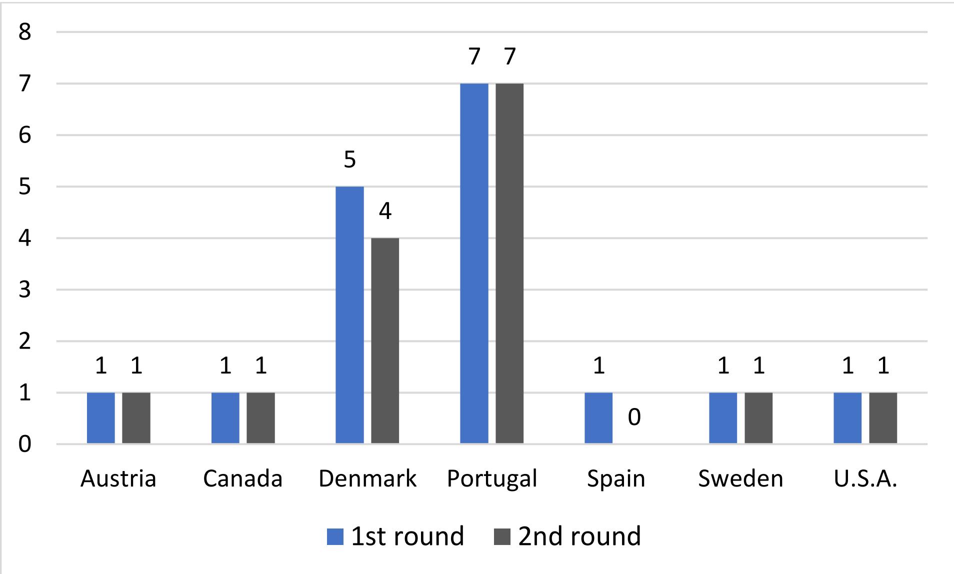


Figure 5-3: Geographic distribution of the respondents, per round (total number).

The participants of the different organizations (figure 5-4) self-defined their areas of expertise, to enable an accurate panel categorization (figure 5-5).

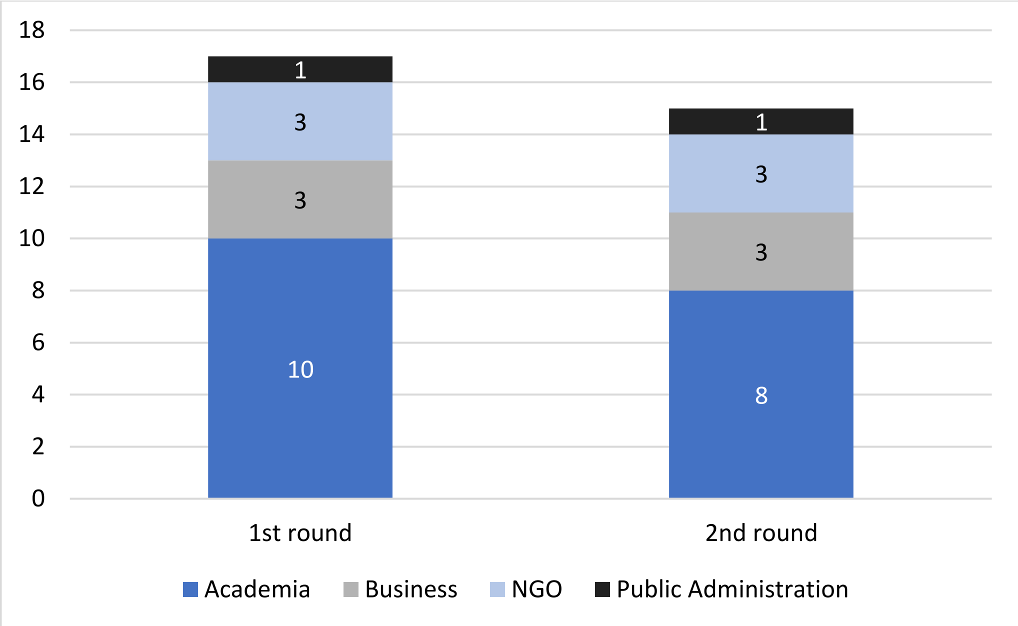


Figure 5-4: Type of organization of the respondents, per round (total number)

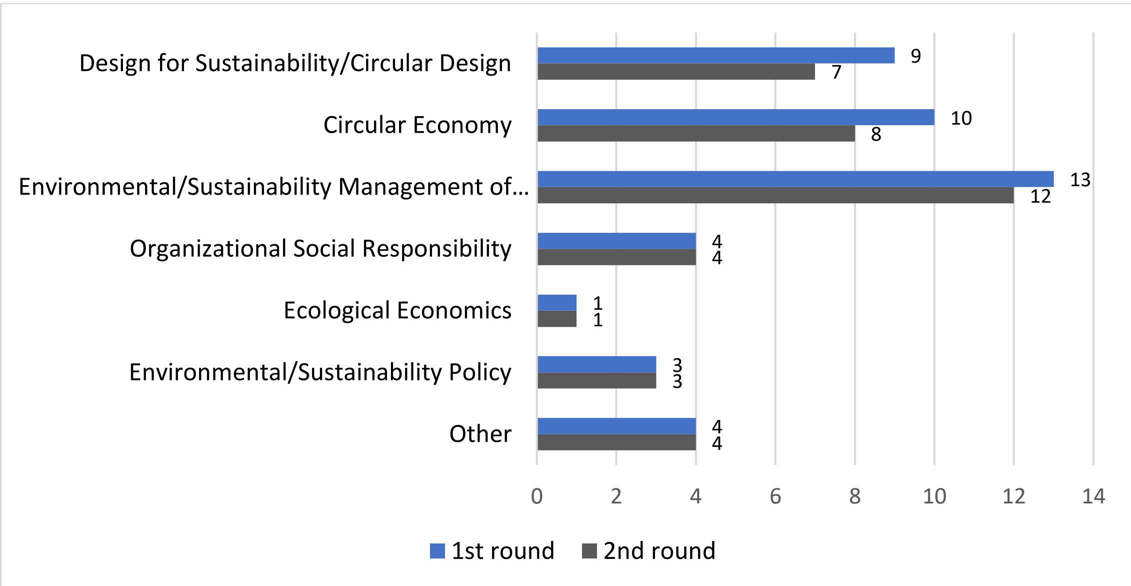


Figure 5-5: Areas of expertise indicated by respondents, per round (multiple choice)

5.4.2 Definition of design for CE in a strong sustainability paradigm

Following the definition of design for CE and strong sustainability, as described in section 5.3.3, figure 5-6.a and table 5-5 show that the level of agreement with the proposed definition was good, but respondents indicated the following reasons to not (strongly) agreeing with it:

- On a more fundamental level, there was criticism regarding the concept itself: the relationship between CE and strong sustainability (as one expert put it, "what is to be included in the 'and'?").
- Other points of criticism concerned the issue of creation of positive environmental, social and economic value: one expert considered that whether humans can have a positive environmental impact depends on the baseline and that the environmental impacts are captured by the condition of "operating within the planetary boundaries", whereas another expert pointed that according to the strong sustainability view, protection of human health and the environment are goals; keeping economy as a goal could lead to less protection (sub-optimization) from a human health and nature protection perspective. Furthermore, it was noticed that in the second paragraph of the definition the social dimension of sustainability was missing.
- Some respondents expressed concerns about the need to focus on regenerating systems and not only resource flows and emphasized the shift from non-renewable to renewable resources.

An attempt was made to address all these concerns and suggestions and thus the following definition of design for CE in a strong sustainability paradigm was presented in the second round of the Delphi method:

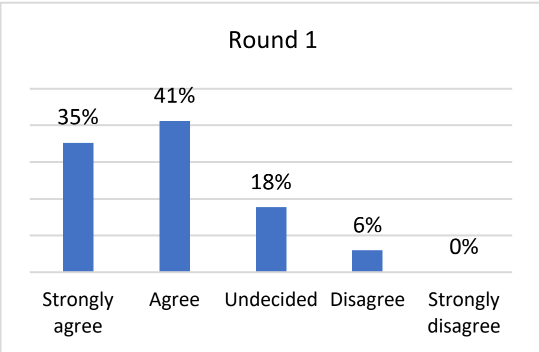
Design of products, product-service systems, business models and production-consumption systems that contribute to a society that thrives within the planetary boundaries, while stimulating social well-being and equity.

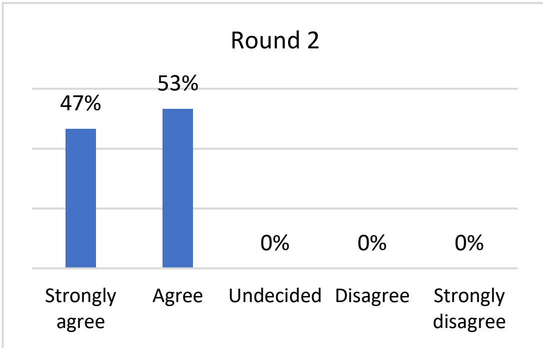
This is accomplished through:

- *Closing, narrowing and slowing resource flows and regenerating natural systems in production, distribution, consumption and post-consumption processes, in cycles energized by renewable sources;*

– *Retaining and creating the highest value and usefulness of materials, equipment and goods for the longest possible time, preferably at the local human scale;*
– *Contributing to a social foundation of wellbeing derived from stakeholders' needs and expectations and internationally agreed social standards.*

The statistical analysis of the results from round 2 (figures 5-6.a and b, and table 5-5) shows an improvement on the level of agreement when compared to the first round, with 100% of respondents agreeing within the top two categories on the five-point Likert scale.





Figures 5-6.a and 5-6.b: Level of agreement of respondents to the proposed definitions of design for a CE and strong sustainability/in a strong sustainability paradigm in the first (a) and the second (b) rounds.

Table 5-5: Statistical analysis of the level of agreement of respondents to the proposed definitions of design for a CE and strong sustainability/in a strong sustainability paradigm in the first and the second rounds

	Round 1	**Round 2**
Mean	4.06	4.47
Median	4	4
Standard deviation	0.90	0.52
Inter-quartile range	1.0	1.0
% strongly agree/agree	76%	100%

These results indicate that experts agreed with the second version of the definition, which is an advancement on the conceptualization of the link between design, CE and strong sustainability and provides the foundations for the development of the model. The definition shares several elements with the concept of circular design:

– Moving away from a product-focused approach towards a business model and a system approach (den Hollander et al., 2017; Moreno et al., 2016; RSA, 2016);

- Closing, narrowing, slowing and regenerating resource flows (Bocken et al., 2016; Konietzko et al., 2020);
- Creating and retaining value (den Hollander et al., 2017).

The agreed definition, however, introduces new elements that reflect a more mature understanding of circular design and the challenge of pursuing a "strong sustainability paradigm":

- The ideas that design should support a thriving and inclusive society functioning within planetary boundaries;
- Favouring a local human scale as opposed to a global scale;
- The consideration of needs and expectations of stakeholders.

These aspects are at the core of the discussion around CE and sustainability and are further discussed in section 5.4.3.

5.4.3 Relationship between CE and strong sustainability

Although the questions concerning definitional aspects were expected to shed light about the relationship between CE and strong sustainability, experts were directly inquired about such relationship, with the aim of guiding the development of the model. In the first round, respondents were asked to openly state features of both concepts that are aligned and features that are conflicting. All experts responded with a minimum of one and a maximum of three features. After analysis and elimination of redundancies, a list of 10 potential alignments and 10 potential conflicts was elaborated, that respondents were asked to rank in the second round (tables 5-6 and 5-7).

Table 5-6: Potential alignments between CE and strong sustainability, in order of ranking (from higher to lower rank)

Potential alignments between CE and strong sustainability
Attempt to stay within planetary boundaries
Focus on reduced consumption of virgin feedstock by keeping resources in closed loops
Positive environmental value through strengthening ecological regeneration
Preserving the value of products, materials and resources as long as possible
Shift to renewable energy
Degrowth

Potential alignments between CE and strong sustainability
Resource efficiency
Job creation and social sustainability
Shift to renewable materials
Sustaining capital stocks over time

Note: The cells in grey indicate that the feature scored above the average.

Table 5-7: Potential conflicts between CE and strong sustainability, in order of ranking (from higher to lower rank)

Potential conflicts between CE and strong sustainability
CE is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model
CE does not imply acting in nested circles: business (and economic activity) fully within social, then all within environmental limits, whereas this is required in strong sustainability
CE does not necessarily include the social sustainability dimension
Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals
The CE features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to substitution of capitals
CE is not addressing a radical change in consumption patterns, required in strong sustainability
CE still promotes GDP growth
With a higher resource efficiency resulting from CE rebound effects can occur, that will lead to an even higher resource use
Circularity might entail keeping toxic substances in the loop
The energy needed for the closing loops is not always included in CE approaches

Note: The cells in grey indicate that the feature scored above the average.

Figures 5-7 and 5-8 present the results of the ranking of potential alignments and conflicts between CE and strong sustainability (the theoretical interval ranges from 150 to 15) and the average value (67,5). The statistical analysis of these answers is given in tables 5-8 and 5-9.

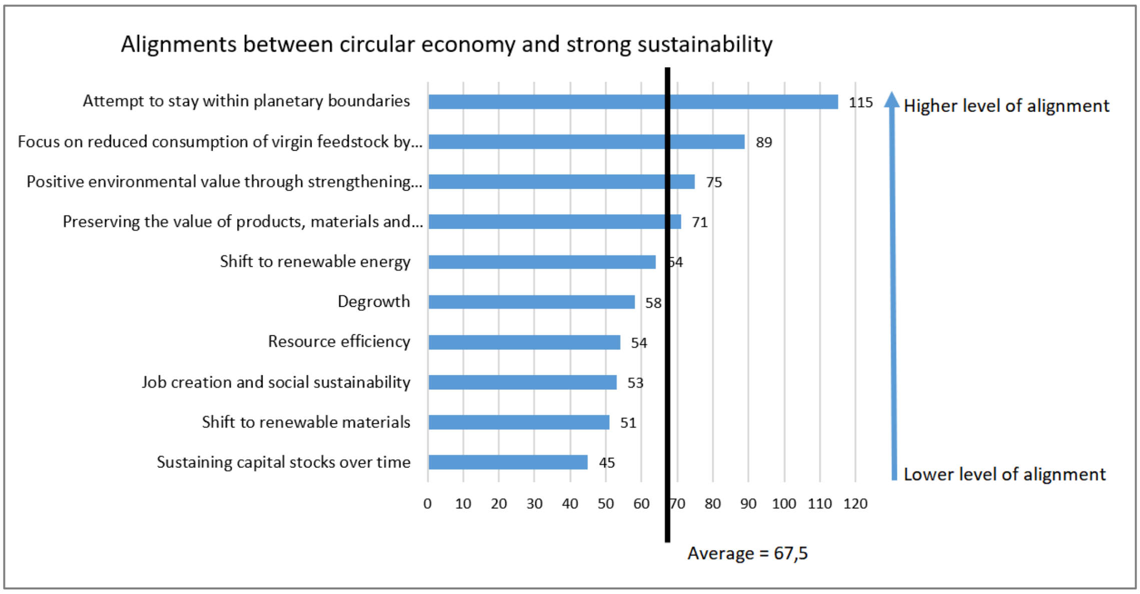


Figure 5-7: Results of the ranking of potential alignments between CE and strong sustainability (second round)

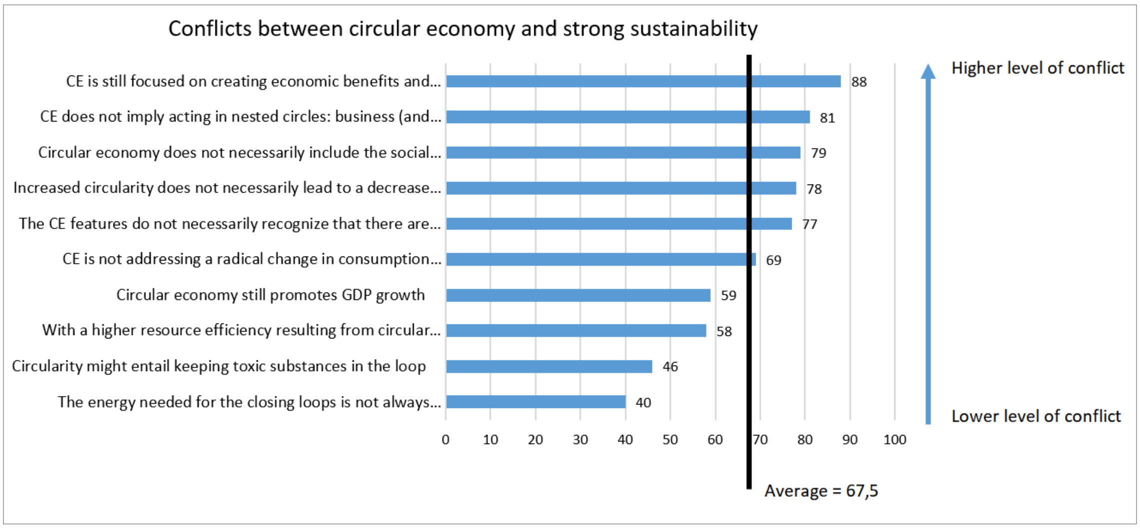


Figure 5-8: Results of the ranking of potential conflicts between CE and strong sustainability (second round)

Table 5-8: Potential alignments between CE and strong sustainability (second round)

Alignments ranking [a]	Mean	Median	% [b]	Standard deviation	Inter-quartile range	Kendall's W
Attempt to stay within planetary boundaries	8,67	10	87%	2,41	1,50	0,22
Focus on reduced consumption of virgin feedstock by keeping resources in closed loops	6,93	7	80%	2,28	3,00	
Positive environmental value through strengthening ecological regeneration	6,00	6	53%	2,67	2,50	
Preserving the value of products, materials and resources as long as possible	5,73	6	60%	2,02	2,50	
Shift to renewable energy	5,27	6	60%	2,99	4,50	
Degrowth	4,87	3	47%	3,56	6,50	
Resource efficiency	4,60	4	33%	3,11	5,50	
Job creation and social sustainability	4,53	4	27%	2,13	2,00	
Shift to renewable materials	4,40	4	27%	1,92	3,00	
Sustaining capital stocks over time	4,00	4	27%	2,70	4,00	

[a] From higher to lower in average

[b] % of experts placing an item in the top half of their list

Table 5-9: Potential conflicts between CE and strong sustainability (second round)

Conflicts ranking [a]	Mean	Median	% [b]	Standard deviation	Inter-quartile range	Kendall's W
CE is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model	6,87	8	67%	2,56	4	0,12
CE does not imply acting in nested circles: business (and economic activity) fully within social, then all within environmental limits; whereas this is required in strong sustainability.	6,40	7	53%	3,50	6	
CE does not necessarily include the social sustainability dimension	6,27	6	67%	2,63	3	
Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals	6,20	7	67%	2,83	5	
The CE features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to substitution of capitals	6,13	7	67%	2,92	4	

Conflicts ranking [a]	Mean	Median	% [b]	Standard deviation	Inter-quartile range	Kendall's W
CE is not addressing a radical change in consumption patterns, required in strong sustainability	5,60	6	60%	2,72	4	
CE still promotes GDP growth	4,93	4	33%	2,96	5	
With a higher resource efficiency resulting from CE, rebound effects can occur, that will lead to an even higher resource use	4,87	5	33%	2,07	2,5	
Circularity might entail keeping toxic substances in the loop	4,07	2	27%	3,13	5	
The energy needed for the closing loops is not always included in CE approaches	3,67	3	20%	2,19	3,5	

[a] From higher to lower in average

[b] % of experts placing an item in the top half of their list

Given the low level of agreement between experts regarding the questions of alignment and conflict between CE and strong sustainability, on a second step we limited a statistical analysis to the features that scored above average, i.e., those in grey in tables 5-6 and 5-7; for that end, we redefined the scoring (from 1 to 4 in the case of the four alignments and from 1 to 6 in the case of the six conflicts, respecting the ranking that had been awarded by the experts). We observed that the level of agreement regarding the alignments increased, reaching the "moderate agreement" level (table 5-10), but as for the conflicts between CE and strong sustainability, the level of agreement decreased (table 5-11).

Table 5-10: Statistical analysis of the potential alignments between CE and strong sustainability, limited to the items that scored above average (second round)

Alignments ranking [a]	Mean	Median	Standard deviation	Inter-quartile range	Kendall's W
Attempt to stay within planetary boundaries	3,47	4	1,06	0,5	0,33
Focus on reduced consumption of virgin feedstock by keeping resources in closed loops	2,47	3	0,99	1,0	
Positive environmental value through strengthening ecological regeneration	2,40	3	1,06	1,5	
Preserving the value of products, materials and resources as long as possible	1,67	2	0,62	1,0	

[a] From higher to lower in average

Table 5-11: Statistical analysis of the potential conflicts between CE and strong sustainability, limited to the items that scored above average (second round)

Conflicts ranking	Mean	Median	Standard deviation	Inter-quartile range	Kendall's W
CE is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model	4,00	4	1,56	1,5	0,03
CE does not imply acting in nested circles: business (and economic activity) fully within social, then all within environmental limits; whereas this is required in strong sustainability.	3,67	4	2,13	4	
CE does not necessarily include the social sustainability dimension	3,47	3	1,88	3	
Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals	3,40	3	1,68	2	
The CE features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to substitution of capitals	3,53	4	1,55	2,5	
CE is not addressing a radical change in consumption patterns, required in strong sustainability	2,93	3	1,53	1,5	

These results must be carefully analysed due to the lack of consensus on the conflicts between CE and strong sustainability, but it is worthwhile to contrast them with the literature that deals with the relationship between the two concepts.

- CE and natural capital: whereas experts considered that both CE and strong sustainability aim at a society that operates within the planetary boundaries (corroborated by Schröder et al., 2019), some agreed that the CE does not imply that there are severe limits to the substitution of natural capital. According to a strong sustainability view, human activities should integrate the nature-given, non-negotiable, physical and environmental restrictions. The society is organized along normative definitions, within which the economy is organized, understood as a constellation of actors and entities providing goods and services for the society. The deductive approach implies that economic actors have to operate within the environmental constraints (Desing et al., 2020b);

- CE within a business case logic: experts stressed that the CE is focused on economic benefits and business opportunities; the business case for sustainability has been criticized since it represents a weak sustainability worldview (Landrum & Ohsowski, 2018), as it derives from a win-win paradigm, where the business case should achieve economic, environmental and social sustainability goals simultaneously. Given the complex nature of sustainable development, Hahn et al. (2010) argue that this is rarely the case and corresponds to a simplistic view in which trade-offs between the three sustainability dimensions are ignored;
- CE and the social dimension of sustainability: it is unclear how CE might affect inequality, power relations in value chains, roles and rights of consumers, users and citizens and the distribution of resources and exploitation of labour (Schröder et al., 2019);
- CE and environmental impacts at global level: there are several arguments questioning the effective contribution of CE to reducing the negative environmental impacts at global level (Geissdoerfer et al., 2018), including the Jevon's paradox: an improved efficiency in raw materials use delivered by the CE will lower the prices and result in increased demand (see for instance Alonso-Jiménez & Regueiro González-Barros, 2022 and Desing et al., 2020b). Therefore, there is a need of complementing the efficiency and effectiveness delivered by the CE with sufficiency (next bullet);
- CE and the need of a radical change in consumption patterns: Respondents expressed concern about the consumption side of CE, which has been under-researched (Camacho-Otero et al., 2018), and the need to address sufficiency and counter the current patterns of consumption. Several authors back up this view (Blomsma & Brennan, 2017; Garcia et al., 2021; Schroeder, 2018). Referring to the famous IPAT equation[9] (Holdren & Enrlich, 1974), Garcia et al., (2021) show that "although population and technological advances can prove to be very helpful in

[9] I (Impact) = P (Population) x A (Affluence) x T (Technology)

achieving sustainable development, they are not sufficient in themselves if the biocapacity consumed per capita (i.e., total consumption) is not addressed" (p. 10), and the CE tends to concentrate in technological improvements (Schröder et al., 2019).

Given the support to the views expressed by the experts during the Delphi exercise found in the literature, those views will be considered in the development of the model (see section 5.5).

5.4.4 Contribution to a model of design for CE in a strong sustainability paradigm and recommendations

In the first round, experts answered an open question about the potential contribution of a model to support companies in developing products, product-service systems, and business models following CE and strong sustainability principles, aiming at understanding the potential added-value they attributed to such model; in addition, respondents were asked what would be required (i.e., which were their recommendations) for this added-value to be accomplished.

Out of the 17 experts, only 12 replied to these questions and all stated potential contributions to be expected from the model. These can be grouped according to four topics; the most mentioned one (5 answers) is related to translating higher level, strong sustainability and CE principles into actionable guidance/design criteria. Experts also mentioned the benefits to the environment and society, including decarbonization of the economy, job creation, less resources use, etc. Two experts proposed that the model should cope with the challenge of promoting strong sustainability in the context of the current economic system that still favours unsustainable businesses, although they recognize that contextual factors such as legislation are a necessary element in the whole picture. And finally, there were answers related to benefits at procedural level, such as the standardisation of concepts and processes, as well as the capability to monitor the progress.

Table 5-12 presents these results, as well as the recommendations that respondents formulated in relation to the contributions they identified.

Table 5-12: Contribution from, and recommendations to, a model of design for a CE in a strong sustainability paradigm

Contribution – aggregated topics	Number of answers	Recommendations: the model should…
Translating higher level, strong sustainability and CE principles into actionable guidance/design criteria	5	…include specific, measurable steps …be developed with a bottom-up approach, using case studies …include life cycle thinking
Benefits to the environment and society	3	…promote systems thinking …include co-creation and involvement of all stakeholders and actors …be flexible to respond to the evolution of needs …be adjusted to the local conditions
Coping with the challenge of aligning strong sustainability with the current economic system, which does not favour that	2	…provide for the development of business models that incorporate understandings of ecological value beyond financial value. …include the notion that the growth of the firm should be deliberately limited. …should start by addressing full sustainability and then to make use of circularity.
Benefits at procedural level	2	…include representative and easy-to-assess monitoring indicators …have specific moments of verification, validation and adjustment in view of the constant evolution of needs

Two experts made a comment saying that without knowing more about the model, they were not able to contribute to this part of the questionnaire, which was a valid point. We decided to record the answers received, and thoroughly consider them in the development of the model but closed these questions after round one.

5.4.5 Elements of the model

In the first round, experts rated the importance of the different elements displayed in figure 5-2, using a 5-points Likert scale. The results in table 5-13 show that there was consensus in scoring all elements as important or very important (scores 4 and 5 in the scale, respectively) and given the high level of agreement, the related questions were closed in round 1.

Table 5-13: Importance of pre-defined elements of a model of design dos CE in a strong sustainability paradigm, distinguishing the strategic, tactical and operational levels of design management in a company.

Pre-defined elements of the model [a]	Mean	Median	Standard deviation	Inter-quartile range	% Likert scale 4-5 Consensus >= 51%
Alignment of the business strategy with the vision (strategic) (see next point)	4,76	5	0,44	0	100%

Pre-defined elements of the model [a]	Mean	Median	Standard deviation	Inter-quartile range	% Likert scale 4-5 Consensus >= 51%
Establishment of a vision for CE and strong sustainability to which the company contributes (strategic)	4,71	5	0,47	1	100%
Integration of design for CE and strong sustainability in management systems and practices (environment, quality, social responsibility, others) (tactical)	4,65	5	0,61	1	94%
Involvement of different internal functions within a company in the design process (tactical)	4,65	5	0,61	1	94%
Stakeholder involvement in establishing the vision, co-development of circular and sustainable solutions, and sustainability assessment (strategic)	4,59	5	0,62	1	94%
Circular and sustainable design strategies and criteria covering environmental, social and economic dimensions (tactical)	4,53	5	0,72	1	88%
Organization of the design and development process for products, product-service systems and business models (operational)	4,47	5	0,72	1	88%
Sustainability and circularity assessment with a life cycle perspective (tactical)	4,35	5	0,79	1	82%

[a] From higher to lower in average

An open question regarding missing elements was posed also in the first round and scored by the respondents in round 2, using the same 5-points Likert scale. The results are given in table 5-14.

Table 5-14: Importance of additional elements of the model, proposed by the experts in the first round.

Additional elements of the model [a]	Mean	Median	Standard deviation	Inter-quartile range	% Likert scale 4-5 Consensus >= 51%
Translating higher-level goals and principles of CE in a strong sustainability paradigm into design criteria	4,80	5	0,41	0	100%
Understanding how the products, product-service systems and business models of the organization interact with the wider socio-ecological system they are part of.	4,67	5	0,49	1	100%
Establishing partnerships with stakeholders to jointly develop products,	4,40	5	0,74	1	87%

Additional elements of the model [a]	Mean	Median	Standard deviation	Inter-quartile range	% Likert scale 4-5 Consensus >= 51%
product-service systems, and business models aligned with CE and strong sustainability principles					
Inclusion of user and consumption perspectives into design processes to integrate them into circular and sustainable solutions principles	4,27	4	0,88	1	87%
Articulation between different individual projects (products, product-service systems, business models) and assessment of how they are interconnected at the company level	3,80	4	0,68	1	67%

a From higher to lower in average

Although experts considered that these elements were missing from the list used in the first round of the Delphi survey, in fact, their proposals (all of which meet the consensus criterion) complement or deepen what was already included in the model (with one exception) as shown in Table 5-15.

Table 5-15: Take aways from the experts' proposals regarding additional elements of the model.

Proposed additional element of the model	Predefined element(s) it relates to	Take aways from the experts' proposals
• **Translating higher-level goals and principles of CE in a strong sustainability paradigm into design criteria**	• Establishment of a vision for CE and strong sustainability to which the company contributes (strategic) • Circular and sustainable design strategies and criteria covering environmental, social and economic dimensions (tactical)	• The model should include not only a vision and goals, but also principles • The model should include mechanisms to transform aspirational goals into concrete design criteria
• **Understanding how the products, product-service systems and business models of the organization interact with the wider socio-ecological system they are part of.**	• Establishment of a vision for CE and strong sustainability to which the company contributes (strategic) • Sustainability assessment (tactical)	• Explicitly include an analysis step required to establish a vision of CE and strong sustainability (strategic level), as well as a review to assess if the vision is being implemented
• **Establishing partnerships with stakeholders to jointly develop products, product-service systems, and business models aligned with CE and strong sustainability principles**	• Stakeholder involvement in establishing the vision, co-development of circular and sustainable solutions, and sustainability assessment (strategic)	• The proposed additional element is very similar to the predefined one
• **Inclusion of user and consumption perspectives into design processes to integrate them into circular and sustainable solutions principles**	• The same as above	• Unlike the previous additional element, this one applies specifically to users and consumers and may imply changing consumption patterns

Proposed additional element of the model	Predefined element(s) it relates to	Take aways from the experts' proposals
• **Articulation between different individual projects (products, product-service systems, business models) and assessment of how they are interconnected at the company level**	• New element	• It can be interpreted as to understand the way new business models development (wider scope) influence the design of product-service systems and of physical products (stricter scope) and vice-versa, and assess their articulation

5.4.6 Synthesis

In order to develop the model, it was deemed necessary to develop a definition of design for CE in a strong sustainability paradigm model (RQ1) and consensus among experts was achieved, with a good level of agreement around the definition proposed in the second round of the Delphi research. Despite this convergence, the identification of the elements of alignment and conflict between CE and strong sustainability (RQ2) proved more difficult, since experts did not reach a consensus regarding the conflicts between both concepts. Nonetheless, their observations were supported by the literature and therefore considered in the development of the model and the drafting of principles included therein.

The experts that participated in the research found that the most important added value of the model (RQ3) is to translate higher level, strong sustainability and CE principles into actionable guidance/design criteria.

And finally, the findings related to RQ4 have shown which are the elements of a model for the implementation of design for circular economy in a strong sustainability paradigm, with a high degree of consensus, at strategic, tactical and operational levels.

5.5 A model of design for a CE in a strong sustainability paradigm

The results achieved with this research indicate that the design of products, product-service systems and business models for a CE in a strong sustainability paradigm requires the adoption of principles that should inform companies' practices, particularly the implementation of design strategies and criteria. In order to comply with a strong sustainability view, such principles should lead to a paradigm change as opposed to incremental efficiency improvements, which implies a long-term planning period (Gaziulusoy, 2015).

This research indicated the need of adding several aspects to existing CE principles (presented in section 2.1) to comply with a strong sustainability model. They are derived from the agreed definition of design for a CE in a strong sustainability paradigm, the experts' opinions regarding the alignments and conflicts between CE and strong sustainability and the suggestion of translating higher-level goals and principles of CE in a strong sustainability paradigm into design criteria, even though there was no specific question in the Delphi survey to this regard.

Thus, we propose a new framing for existing CE principles, as proposed by Ellen MacArthur Foundation (2015), and the inclusion of additional principles, as follows:

Overarching principle: **Function within planet boundaries, set up science-based goals and seek a positive environmental impact at the system level, when:**

1. Preserving and enhancing natural capital by controlling finite stocks and balancing renewable resource flows;
2. Optimising resource yields by circulating products components and materials in use at the highest utility at all times in both technical and biological cycles;
3. Fostering system effectiveness by revealing and designing out negative externalities;
4. Developing circular business models oriented to nature conservation;
5. Deliberately limiting the growth in production and consumption, through innovative business models and influencing consumer practices towards sufficiency;
6. Giving priority to the local human scale and shorter circular value chains;
7. Stimulating social well-being by linking circular solutions to stakeholders' needs and expectations and agreed social standards (e.g., the Sustainable Development Goals).

As for the elements of the model, the results also indicate that these are adequately organized at strategic, tactical and operational levels. Furthermore, although the model is targeting individual companies, the systemic nature of CE requires cooperation and co-creation within the value network, considering and positively influencing the environmental, social and economic implications at the system level. Correspondingly, the model encompasses three dimensions, as shown in figure 5-9:

- Complexity: paradigm change and practice change (inspired by Korhonen et al., 2018)
- Organizational levels: strategic, tactical and operational (Rocha et al., 2019)
- Organizational width: single company and the value network, understood as a network of interlinked value chains and interested parties (ISO, 2023).

Table 5-16 shows how the elements of the model relate to the three dimensions and figure 5-9 illustrates the concept of the proposed model operating within the principles.

Table 5-16: Elements of a model of design for a CE in a strong sustainability paradigm.

Dimensions / Elements of the model	Complexity		Levels			Width	
	Paradigm change	Practice change	Strategic	Tactical	Operational	Individual	Value network
Vision (1)	✓		✓			✓	✓
Strategic sustainability assessment (2)		✓	✓			✓	✓
Integration in business strategy (3)	✓		✓			✓	✓
Design strategies and criteria (4)	✓			✓		✓	✓
Co-design of products, PSS and BM (5)		✓	✓	✓	✓	✓	✓
Articulation of projects at company level (6)	✓		✓			✓	
Tactical sustainability assessment (7)		✓		✓		✓	✓
Integration in m'gmt systems and practices (8)		✓	✓	✓	✓	✓	✓
Organization of the D&D process (9)		✓			✓	✓	

(1) Establishing a vision for CE and strong sustainability, to which the company contributes through its business strategy, with a long-term perspective.

(2) Understanding how the products, PSS and BM interact with the wider ecological, social and economic system.

(3) Integration of the principles of CE in a strong sustainability paradigm in the business strategy, at the highest level; this implies questioning the social function of the company in a sustainable society.

(4) Adopting design strategies and criteria aligned with the principles. This implies a hierarchical approach considering giving priority to use- and result-oriented strategies, offering products as services, over the product-oriented strategies (see point 9).

(5) Involving the different internal functions and the external stakeholders, including the value network and user and consumer perspectives.

(6) Articulation between different individual projects and how they are interconnected at company level.

(7) Sustainability assessment of individual projects and their interconnection at company level.

(8) Integration of the model with existing management systems and practices, to ensure the continuity, review and improvement of its implementation.

(9) Structuring the design and development (D&D) process to meet the remaining elements of the model, i.e., definition of the goals, steps, responsibilities and authority and assessment criteria. It should include an explicit initial activity of questioning the function, or the need, that the product or product-service combination should fulfil.

Figure 5-9 presents an overview of the model informed by the principles of CE in a strong sustainability paradigm.

Principles of CE in a strong sustainability paradigm

Function within planet boundaries, set up science-based goals and seek a positive environmental impact, when:

1. **Preserving and enhancing natural capital by controlling finite stock and balancing renewable resource flows.**
2. **Optimising resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles.**
3. **Fostering system effectiveness by revealing and designing out negative externalities.**
4. **Developing circular business models oriented to ecological regeneration.**
5. **Deliberately limiting the growth in production, through innovative BM and influencing consumer practices towards sufficiency.**
6. **Giving priority to the local human scale and shorter circular value chains.**
7. **Stimulating social well-being by linking circular solutions to stakeholders needs and expectations and agreed social standards (e.g., the Sustainable Development Goals).**

Dimensions / Elements of the model	Complexity		Levels			Width	
	Paradigm change	Practice change	Strategic	Tactical	Operati-onal	Individual	Value network
Vision	✓		✓			✓	✓
Strategic sustainability assessment		✓	✓			✓	✓
Integration in business strategy	✓		✓			✓	✓
Design strategies and criteria	✓			✓		✓	✓
Co-design of products, PSS and BM		✓	✓	✓	✓	✓	✓
Articulation of projects at company level	✓		✓			✓	
Tactical sustainability assessment		✓		✓		✓	✓
Integration in m'gmt systems and practices		✓	✓	✓	✓	✓	✓
Organization of the D&D process		✓			✓	✓	

Figure 5-9: A model of design for the CE in a strong sustainability paradigm.

When compared with the initial framework (figure 5-2) this model presents similar elements. Nevertheless, it is worthy to note the following:

- The strategic sustainability assessment (new element) helps companies to understand how their products, PSS and BM contribute to the sustainability vision and responds to a specific recommendation rated as very important by experts in the Delphi survey;
- A second new element, also considered as important, is the articulation of projects at company level, to ensure an integrated approach and the alignment of the overall business strategy with the vision and principles;
- The stakeholder involvement element of the previous model is now consubstantiated in specific activities of co-design of products, PSS and BM;
- As stated, all elements are informed by the proposed principles of CE in a strong sustainability paradigm, which is perhaps the most important feature that responds to the need of explicitly aligning design models and frameworks with strong sustainability.

5.6 Conclusions

There is a shift both in research and in policy development areas towards adopting strong sustainability as opposed to a weak sustainability paradigm (Ayse Idil Gaziulusoy, 2010; Lefstad, 2021). This research addresses this trend by contributing to the conceptual development of circular design as well as to its practice within a framework of strong sustainability, and therefore attempting to overcome recognized limitations in the current predominant CE and circular design discourses. A more radical approach is deemed necessary, when new research recently published in the journal Science Advances shows that six of the nine planetary boundaries are transgressed, suggesting that Earth is now well outside of the safe operating space for humanity to strive (Richardson et al., 2023).

The research questions and objectives of this work were dealt with through input from a group of experts, obtained using the Delphi method. Although several measures were taken to avoid biases, the limitations of this method still condition our results, since a Delphi study is highly contextual and difficult to replicate (de Jesus et al., 2019).

From a conceptual point of view, it should be highlighted that experts agreed on a new definition of design for CE in a strong sustainability paradigm and identified features that are aligned between the two concepts (CE and strong sustainability). The identification of conflicting features has proved more controversial since no consensus was reached and should be subject of further research.

From a practical perspective, our research resulted in a new model of design for CE in a strong sustainability paradigm. The advantage of this model, when compared to existing approaches, is two-fold: (a) informed by a new set of strong sustainability-related principles that add to existing CE principles, it is expected to provide a sounder framework for companies and their value networks to develop products, product-service systems and business models that ultimately preserve and regenerate the planet and contribute to a social foundation of well-being; and (b) provides management elements that address different degrees of complexity, organizational levels and organizational width, thus attempting to tackle a gap in many CE and circular design approaches found in the literature that lack guidance on how to manage the implementation of visions and strategies. As for prospects of future research, they mostly concern the further specification and testing of the model and its guiding principles in practical applications, considering multiple dimensions: their effectiveness in achieving the desired outcomes in organizational and value network contexts, enablers and obstacles, and success and unsuccess factors.

6

CONCLUSIONS AND RECOMMENDATIONS

"There is no favourable wind for the sailor who doesn't know where to go."
— Seneca

This thesis represents a trajectory that started with the study of design for sustainability (DfS) and moved towards design for circular economy. At this point, it is important to emphasize that the impetus throughout this work has always been the quest for a significant change (in quantitative and qualitative terms) in the way companies innovate their products, services and business models aiming at sustainability.

This research is a starting point, not an end. It has the novelty of proposing a model with the explicit aim of combining design, circular economy and strong sustainability and reflects an evolution of the DfS and circular economy concepts over time. This may be concluded when observing the several definitions that can be found in the previous chapters: DfS in section 3.2; design for CE in sections 4.1 and 5.2.2; design for CE and strong sustainability in section 5.3.3, and design for CE in a strong sustainability paradigm in section 5.4.2. The common denominator is the attempt of keeping a holistic and systemic perspective as opposed to reductionist understandings that would not be aligned with what sustainable development entails.

In the following sections, the main findings and results of this research are summarized.

6.1 A reflection on the analysis of DfS models

Through the combination of design management and corporate sustainability management it was possible to develop an analytical framework to analyse DfS models, consisting of elements at three levels:

- Strategic (overall policies, missions and agendas of organizations),
- Tactical (teams, processes and systems of specific business units or functions), and
- Operational (tasks relevant to the undertaking of individual projects).

These levels are drawn from design management theory (Best, 2015; Antunes, 2012; Staples, 2008). The specification of the elements and respective guiding questions derived from corporate sustainability management (Baumgartner, 2014; ISO, 2010; Robèrt et al., 2002; Robèrt, 2000). The development of the framework responded to RQ1.1, SQ 1.1.a).

The application of the framework to the ten published DfS models found through an extensive literature review showed that it captured most of models' features, and allowed also to understand how they varied in the approaches used to put DfS into practice, as well as to identify gaps and common elements (RQ 1.1, SQ 1.1.b). The findings have been systematically compared with literature, which supported them in most cases, and we concluded that further development is mostly needed for the following elements of the models:

- Establishment of a sustainability vision for DfS: the variety of solutions found reflects the lack of a common understanding on how to operationalize sustainability at the micro level, using backcasting, forecasting or both methods, taking a normative stance by proposing to broad principles, recommending stakeholder consultation processes, and different combinations of these methods.
- Integration of DfS in the business strategy: some of the models focus on the alignment of DfS with existing business goals and strategies, whereas others go beyond, questioning the purpose of the business in order to innovate towards sustainability.
- Stakeholder involvement: literally all models include this element, but the degree of involvement ranges from simple mapping and consultation to co-creation; they also differ on which stakeholders to be involved, from those in the value chain to the society as a whole.

- Environmental, social and economic criteria and strategies for DfS: it was observed that (i) environmental criteria tend to be more emphasized than the two other dimensions, (ii) the studies models showed a very unalike approach to design strategies and (iii), although most models recognize the existence of trade-offs between sustainability criteria, only one provided guidance on how to deal with them, i.e., through the focus on critical sustainability impacts and having overarching sustainability principles as guiding principles.
- Sustainability assessment: almost all models recommended qualitative or semi-quantitative life cycle evaluation methods using matrixes or checklists that enable an assessment in the early stages of the design process, when there is not enough information to perform quantitative life cycle assessments (environmental and social), as well as life cycle costing studies. In some of the models, a combination of qualitative and quantitative methods was proposed. The assessment criteria proposed by the models also showed a noticeable variety.

These findings were a stepping stone to the progress of the research. Together with the inclusion of circular economy and circular design in the project, they have led to the formulation of the remaining research questions. It was interesting to observe that the analytical framework could be applied to DfS models with different innovation levels (product improvement and innovation, function innovation and system innovation); thus, it was used as a departure point for the development of the model of design for CE in a strong sustainability paradigm (RQ 1).

6.2 A reflection on circular design strategies and criteria

In the framework of circular economy, there is a vast amount of scientific and grey literature providing guidance on design strategies (Bocken et al., 2016; Camocho, 2022; De Groene Zaak & Ethica, 2015; Devadula & Chakrabarti, 2015; Diaz et al., 2021; Konietzko et al., 2020; Lindgreen et al., 2020; Moreno et al., 2016; Pigosso & McAloone, 2021). Nevertheless, with RQ 1.2, we tried to address features that were not completely covered by most of existing publications, that is, including the social dimension of sustainability, envisaging not only product, but also product-service design and including materials and energy sustainability.

Eight circular design strategies and 72 associated criteria have been developed in response to RQ 1.2 and have been presented in chapter 4. The relationship with the life cycle stage they mostly relate to (pre-use phase, use phase and post-use phase) and the circularity goal they most directly contribute to (slowing loops, narrowing loops and closing loops) is presented.

The proposed strategies have been applied in several workshops with practitioners from industry, public administration, consultancy, etc.; nevertheless, since these workshops were not thoroughly reported, their results could not be included in the present research, which corresponds to a limitation of this work.

Furthermore, the circularity aim of regenerating resource loops was overlooked and that is due to the nature of the project within which the strategies were developed: taking the distinction between the biological cycle and the technical cycle of circular economy (Braungart et al., 2007; Ellen MacArthur Foundation, 2015; Morseletto, 2020), the project focused on the technical cycle, and this was the reason why strategies to regenerate resource loops were not included. Anyway, the concern of facilitating the separation of biological from technical materials is included in the design for recycling strategy.

The proposed strategies combine product design and product-service system (PSS) design and it should be remarked that PSS require physical products, which means that these products should also be designed according to the applicable circularity strategies, in order to achieve the potential benefits of the PSS solution (Ceschin & Gaziulusoy, 2016).

The circular design strategies and related criteria are one of the elements of the model developed in chapter 5, which requires a hierarchical approach that prioritizes use-and result-oriented strategies over product-oriented strategies and questions the function or the need that the product or product-service combination fulfil, with a view of dematerializing the system.

6.3 A reflection on design for CE and strong sustainability

This thesis is expected to have made an important contribution to conceptualize design for CE in a strong sustainability paradigm. With the support of literature review and experts' organized inputs through surveys using a Delphi forecasting method in two rounds, the following new definition was elaborated (RQ 1.3), with a high level of consensus among experts:

Design of products, product-service systems, business models and production-consumption systems that contribute to a society that thrives within the planetary boundaries, while stimulating social well-being and equity.

This is accomplished through:

- *Closing, narrowing and slowing resource flows and regenerating natural systems in production, distribution, consumption and post-consumption processes, in cycles energized by renewable sources;*
- *Retaining and creating the highest value and usefulness of materials, equipment and goods for the longest possible time, preferably at the local human scale;*
- *Contributing to a social foundation of wellbeing derived from stakeholders' needs and expectations and internationally agreed social standards.*

This definition is in accordance with the notion of non-substitutability of capitals (Ekins et al., 2003) by framing design within the planetary boundaries (Rockström et al., 2009; Steffen et al., 2015), attends to the need of providing a social base of welfare for all (Raworth, 2017), addresses the circularity goals of closing, narrowing, slowing and regenerating resource flows (Konietzko et al., 2020), implies a hierarchy in design strategies in which those that retain the highest value of materials and products (Reike et al., 2018) should be prioritized, includes the energy dimension (Haas et al., 2015) and calls for the respect for stakeholders' needs and expectations (Rocha & Schmidt, 2014).

At this stage, it makes sense to question the difference between this definition and the concept of DfS. The answer is not straightforward, given that DfS itself is not universally defined. However, there are some considerations that matter to the question:

- Circularity can be seen as a socio-technical approach to DfS, which involves revising the alignment between organizational cultures and product-development processes and has the potential to contribute to avoid the tendency towards incremental improvements to existing products (Diaz et al., 2021); according to this view, CE contributes to a better DfS process;
- On the other hand, DfS approaches such as cradle-to-cradle design (Braungart et al., 2007), product-service systems design (Stahel, 2016; Tukker, 2015) and design for systems innovations and transitions (Ceschin & Gaziulusoy, 2016) can

contribute to CE respectively through (i) the selection of materials and product designs that foster closed loops in material flows, (ii) promoting business models that support CE and (iii) proposing "alternative forms of CE for new socio-technical system scenarios" (Ceschin & Gaziulusoy, 2016, p. 147).

The two concepts (design for CE in a strong sustainability paradigm and DfS) are undoubtedly intertwined, but perhaps what is important to highlight is that design for CE is the design approach that works in (and contributes to) the context of a circular model of production and consumption, that aims at drastically reducing the dependence from virgin, non-renewable materials (this context was not clearly defined, e.g. at policy level, when academics and practitioners started working in DfS); and that by including the strong sustainability idea, it is a design approach that contributes to a societal model that preserves a given stock of natural assets (Sauvé et al., 2016). With the definition of the planetary boundaries and their thresholds (Richardson et al., 2023; Rockström et al., 2009; Steffen et al., 2015), such given stock of natural assets is a much more tangible idea.

As a matter of fact, in the debate among experts on the elements of alignment and conflict between CE and strong sustainability (RQ 1.4), (i) the attempt to stay within planetary boundaries, (ii) the focus on reduced consumption of virgin feedstock by keeping resources in closed loops, (iii) a positive environmental value through strengthening ecological regeneration and (iv) the preservation of the value of products, materials and resources as long as possible were considered aspects that go hand in hand in both concepts. As for elements of conflict or misalignments (the respondents indicated both in the open question of the first round), consensus was not reached, which would have been of even more interesting, since it would have helped to clarify any additions or conditions that the model should attend to. Nonetheless, the received answers were supported by literature.

RQ 1.5 concerned the added value of a model that supports companies in the design for CE in a strong sustainability paradigm. The most important outcome was the translation of higher level, strong sustainability and CE economy principles into actionable guidance and criteria.

Since such principles do not exist, they were developed as part of the construction of the model and constitute an additional contribution of the present research. This leads us to the overarching RQ1 of this thesis: *What should a model that supports companies in the systematic adoption of design for circular economy in a strong sustainability paradigm look like?*

This part of the work was equally subject of the consultation process using the Delphi method and the model's elements in the survey were based on the analytical framework developed in chapter 3 to study DfS models, as mentioned above. The result was a model with overarching principles and nine elements that were organized as follows:

- Induce a paradigm change (in terms of norms, values, world views, visions and concepts), a practice change (tools, metrics, instruments, indicators, measures) (Korhonen et al., 2018) or both;
- Concern the strategic, tactic and operational levels of the organization (Rocha et al., 2019);
- Concern the single company or the value network also (Korhonen et al., 2018; ISO 2023).

The specification of the different elements and their application was not part of the present research, which is a limitation and, simultaneously, a perspective for future research. The same applies to the way the principles inform the different elements of the model. Nevertheless, it is possible to draw the following considerations about the model:

- The relationship between this model and schemes for corporate sustainability management (such as environmental management systems, quality management systems, etc.) is familiar to companies, thus increasing the possibilities of implementation (Kristensen et al., 2021); furthermore, it addresses a gap in CE and circular design approaches that lack guidance on how to manage the implementation of visions and strategies (Pigosso & McAloone, 2021).
- The model pays particular attention to activities at strategic level, which is in accordance to Baumgartner & Rauter (2017) views that there is a lack of strategic orientation in current sustainability management and that this is deterring companies' progress to sustainability. Diaz et al. (2021) suggest that greater emphasis should be placed on addressing CE during strategic product (PSS and BM) planning. At this level, there is a greater potential for the involvement of actors that can influence more innovative solutions.
- There will be implications of the new model in the detailed design and development process, namely:
    - As indicated in chapter 5, in the beginning of the process the design team (that involves different internal functions and the external stakeholders,

  including the value network and the user and consumer perspectives) should question the function or the need that the product-or product service combination should fulfil. This allows the opening up for solutions with higher sustainability potential, such as function innovation and system innovation (Brezet, 1997), addressing the principles presented in this thesis.
  - The alignment of each project with the principles requires a significant amount of knowledge about the sustainability performance of the products, product-service systems and business models of the organization. This is one of the most important aspects; a variety of new capabilities are required to design for a sustainable future (De los Rios & Charnley, 2017);
  - This model places design at strategic level and therefore the design and development team should apply design strategies and criteria aligned with the principles and vision of the organization and its stakeholders. A first approach of circular design strategies and criteria has been presented in chapter 4, but they need to be further developed to accompany the principles here proposed;
  - The model includes the aspect of co-design with stakeholders. Camocho (2022) remarks the importance of co-creation to reach disruptive innovations in design for a circular economy and for example, Pedersen et al. (2023) propose an actionable staging approach to co-create business models with value networks.
- As for the assessment, which is essential to support the decision making, it is suggested that it should be performed at two levels: strategic, with the aim of understanding how the products, PSS and BM interact with the wider, ecological and social system, and tactical, at individual project level. As stated before, often it is not possible to perform quantitative sustainability assessments due to the lack of data; on the other hand, once such data is available, the solution is already developed and it is difficult to make any changes in view of the assessment's results. This implies a learning process in organizations. Considering that the scope in the model is wide (environmental, social and economic dimensions applied to products, PSS and BM, as well as the organization as a whole) the assessment work is

extremely important and challenging. To this adds the fact that new areas of concern, to which there are no indicators in traditional life cycle assessments and life cycle costing, such as planetary boundaries (for sustainability reporting including planetary boundaries indicator, see Erlandsson et al., 2023) or SDG (see Cordella et al., (2023) on life cycle sustainability assessment and SDG).

6.4 A model of design for CE in a strong sustainability paradigm, limitations and perspectives to further work

As shown in the previous sections, this thesis provides an answer to *RQ1: What should a model that supports companies in the systematic adoption of design for circular economy in a strong sustainability paradigm look like?*, in a conceptual way. Being the first attempt to develop a model with the level of demands as the one we are dealing with, to the knowledge of the author, this is logical first step.

The limitations in the construction of the new model have been identified throughout the text: (i) regarding the development of the analytical framework in chapter 3, mostly in relation to the exclusion criteria that were used when identifying the models for analysis; (ii) in the activities presented in chapter 5, that relied on the Delphi consultation process (given the limitations of the method itself); and (iii) fact that the proposed design strategies and the new model and associated guiding principles were not subject of a test phase.

These limitations were to some extent compensated by the very extensive literature review, which allowed to create a sound body of knowledge around the matters under study.

The fact that the model was not tested was due to practical reasons. This work has been very exhaustive, and the decision was to leave a potential testing phase to a next step beyond the present PhD research. Given the level of ambition and broadness of the model, one promising way would be to apply it to specific sectors, allowing to be more specific regarding the reality of products, PSS and BM opportunities in the sectors, the body of knowledge in terms of the related sustainability impacts and the context in relation to current and future legislation, market and consumer behaviour, socio-technical characteristics, etc. The EU Action Plan on Circular Economy (European Commission, 2020) and the new Portuguese Action Plan on Circular Economy 2023-2027 (under public consultation, see Agência Portuguesa do Ambiente

& Direção Geral das Atividades Económicas, 2023) indicate priority sectors/need areas in Europe and in Portugal that may serve as a basis for selecting areas for future work.

Given that there is an intentional relationship between this model and schemes for corporate sustainability management, it would be interesting to study how the former can be integrated in the European Foundation for Quality Management (EFQM) Model. Based on the link between organizations' purpose and strategy, the EFQM 2020 version is aligned with the United Nations Sustainable Development Goals and calls for an effective leadership in order to understand and adopt the excellence principles in the long term with a view to future requirements, deliver performance and manage transformation, focusing on the 'ecosystem' in which the organization operates and delivering outstanding results (Fonseca, 2022; Murthy, 2022). It is, therefore, an interesting model whose links to the one presented in this thesis seem worthy to study.

Another trend that is relevant for the application of the model here proposed is Industry 5.0, a value-oriented, human-centred industry (Longo et al., 2020) with the aim of achieving sustainable and resilient systems (Alves at al., 2023). The role of the model in pursuing Industry 5.0 is also an avenue for further research.

Finally, it would be important to assess the sustainability impacts of the development of products, product-service systems and business models according to the proposed model, using the Planetary Boundaries as environmental sustainability reference (Hellweg et al., 2023; Bjørn et al., 2015) ascertain its value in delivering sustainable solutions, as well as to understand the necessary changes at societal level that provide the context for the model to achieve the desired outcomes.

REFERENCES

Accenture (2014). Circular Advantage: Innovative business models and technologies to create value in a world without limits to growth. Accenture. Retrieved 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

Achterberg, E., Hinfelaar, J., & Bocken, N. (2016). The Value Hill Business Model Tool : identifying gaps and opportunities in a circular network.

Agência Portuguesa do Ambiente, & Direção Geral das Atividades Económicas. (2023). Plano de Ação para a Economia Circular (PAEC). https://participa.pt/pt/consulta/plano-de-acao-para-a-economia-circular-paec

Ahmad, S., Wong, K.Y., Tseng, M.L., Wong, W.W. (2018). Sustainable product design and development: A review of tools, applications and research prospects. Resour. Conserv. Recycl. 132, 49–61.

Ajukumar, V. N., & Gandhi, O. P. (2013). Evaluation of green maintenance initiatives in design and development of mechanical systems using an integrated approach. Journal of Cleaner Production, 51, 34-46. https://doi.org/10.1016/j.jclepro.2013.01.010

Alhawari, O., Awan, U., Bhutta, M. K. S., & Ali Ülkü, M. (2021). Insights from circular economy literature: A review of extant definitions and unravelling paths to future research. Sustainability (Switzerland), 13(2), 1–22. https://doi.org/10.3390/su13020859

Ali, F., Boks, C., Bey, N. (2016). Design for Sustainability and Project Management Literature - A Review. Procedia CIRP 48, 28–33. doi:10.1016/j.procir.2016.04.185

Alonso-Jiménez, A., & Regueiro González-Barros, M. (2022). The paradox of the circular economy in the raw materials industry. E3S Web of Conferences, 349(May), 01003. https://doi.org/10.1051/e3sconf/202234901003

Alves, J., Lima, T.M. & Gaspar, P.G. (2023). Is Industry 5.0 a Human-Centred Approach? A Systematic Review. Processes 11(1). https:// doi: 10.3390/pr11010193

Ameta, G. (2009). Design for Sustainability: Overview and Trends, in: International Conference on Engineering Design, ICED'09. Sanford, CA.

Andrews, D. (2015). The circular economy, design thinking and education for sustainability. Local Economy, 30(3), 305–315. https://doi.org/10.1177/0269094215578226

Antikainen, R., Lazarevic, D., & Seppälä, J. (2018). Circular Economy: Origins and Future Orientations. In H. Lehman (Ed.), Factor X Challenges, Implementation Strategies and Examples for a Sustainable Use of Natural Resources (pp. 115–129).

Antunes, R.J.F. (2012). Práticas de Gestão do Design para o Subsetor Nacional de Cerâmica Utilitária e Decorativa. Tese de Doutoramento. Universidade de Aveiro.

Armistead, C., & Clark, G. (1992). The balancing act, Managing Service Quality: An International Journal, Vol. 2 Issue: 2, pp.115-119, https://doi.org/10.1108/09604529210029173

Arnette, A.N., Brewer, B.L., Choal, T. (2014). Design for sustainability (DFS): The intersection of supply chain and environment. J. Clean. Prod. 83, 374–390. doi:10.1016/j.jclepro.2014.07.021

Avella, J. R. (2016). Delphi panels: Research design, procedures, advantages, and challenges. International Journal of Doctoral Studies, 11, 305–321. https://doi.org/10.28945/3561

Bakker, C., Den Hollander, M., Van Hinte, E., & Zijlstra, Y. (2014). Products that last - Product design for circular business models. TU Delft Library, Delft, The Netherlands.

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

Baldassarre, B., Calabretta, G., Bocken, N., Diehl, J. C., & Keskin, D. (2019). The evolution of the Strategic role of Designers for Sustainable Development. Conference Proceedings of the Academy for Design Innovation Management, 2(1). https://doi.org/10.33114/adim.2019.01.228

Baumgartner, R. J., & Rauter, R. (2017). Strategic perspectives of corporate sustainability management to develop a sustainable organization. Journal of Cleaner Production, 140, 81–92. https://doi.org/10.1016/j.jclepro.2016.04.146

Baumgartner, R.J. (2014). Managing corporate sustainability and CSR: A conceptual framework combining values, strategies and instruments contributing to sustainable development. Corp. Soc. Responsib. Environ. Manag. 21, 258–271. doi:10.1002/csr.1336

Behrendt, S., Jasch, C., Peneda, M.C., van Weenen, H. (1997). Life Cycle Design, A Manual for Small and Medium-sized Enterprises. Springer, Berlin.

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S., & Schroeder, P. (2018). Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency. Sustainability Science, 13(6), 1533–1547. https://doi.org/10.1007/s11625-018-0582-1

Best, K. (2006). Design Management: Managing Design Strategy, Process and Implementation.

Best, K. (2015). Design Management: Managing Design Strategy, Process and Implementation, 2nd Edition. ed. Fairchild Books.

Bjørn, A., Diamond, M., Owsianiak, M., Verzat, B. & Hauschild, M.Z. (2015). Strengthening the link between life cycle assessment and indicators for absolute sustainability to support development within planetary boundaries. Environmental Science and Technology, 49(11), 6370-6371. https:// 10.1021/acs.est.5b02106.

Bjørn, A., & Røpke, I. (2018). What does it really mean to be a strongly sustainable company? – A response to Nikolaou and Tsalis. Journal of Cleaner Production, 198, 208–214. https://doi.org/10.1016/j.jclepro.2018.06.268

Blizzard, J.L., Klotz, L.E., Klotz, L.E. (2012). A framework for sustainable whole systems design. Des. Stud. 33, 456–479. doi:10.1016/j.destud.2012.03.001

Blomsma, F., & Brennan, G. (2017). The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. Journal of Industrial Ecology, 21(3), 603–614. https://doi.org/10.1111/jiec.12603

Blomsma, F., Pieroni, M., Kravchenko, M., Pigosso, D. C. A., Hildenbrand, J., Kristinsdottir, A. R., Kristoffersen, E., Shabazi, S., Nielsen, K. D., Jönbrink, A. K., Li, J., Wiik, C., & McAloone, T. C. (2019). Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation. Journal of Cleaner Production, 241. https://doi.org/10.1016/j.jclepro.2019.118271

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. https://doi.org/10.1080/21681015.2016.1172124

Borja de Mozota, B. (2008). A Theoretical Model for Design in Management Science : The Paradigm Shift in the Design Profession, from Management as a Constraint to Management Science as an Opportunity. Design Management Journal, 3(1), 30–37.

Boulkedid, R., Abdoul, H., Loustau, M., Sibony, O., & Alberti, C. (2011). Using and Reporting the Delphi Method for Selecting Healthcare Quality Indicators: A Systematic Review. PLOS ONE, 6(6), 1–9. https://doi.org/10.1371/journal.pone.0020476

Brezet, H. (1997). Dynamics in ecodesign practice. Ind. Environ. 20, 21–24.

Brezet, H., van Hemel, C. (1997). EcoDesign: A promising approach to sustainable production and consumption. UNEP, Paris.

British Standards Institute (2017). BS 8001:2017. Framework for Implementing the Principles of the Circular Economy in Organizations - Guide. The British Standards Institution, London.

British Standards Institute. (2017). BS 8001:2017 Framework for implementing the principles of the circular economy in organizations – Guide (p. 81). British Standard Institute.

Brones, F., Monteiro de Carvalho, M. (2015). From 50 to 1: integrating literature toward a systemic ecodesign model. J. Clean. Prod. 96, 44–57. doi:10.1016/j.jclepro.2014.07.036

Brown, B. B. (1968). Delphi process: a methodology used for the elicitation of opinions of experts. In ASTME Vectors (Issue February, p. 18). The RAND Corporation.

Brozovic, D. (2020). Business model based on strong sustainability: Insights from an empirical study. Business Strategy and the Environment, 29(2), 763–778. https://doi.org/10.1002/bse.2440

Buchert, T., Neugebauer, S., Schenker, S., Lindow, K., Stark, R. (2015). Multi-criteria decision making as a tool for sustainable product development - Benefits and obstacles. Procedia CIRP 26, 70–75. doi:10.1016/j.procir.2014.07.110

Byggeth, S., Broman, G., Robèrt, K.-H. (2007). A method for sustainable product development based on a modular system of guiding questions. J. Clean. Prod. 15, 1–11. doi:10.1016/j.jclepro.2006.02.007

Byggeth, S., Hochschorner, E. (2006). Handling trade-offs in Ecodesign tools for sustainable product development and procurement. J. Clean. Prod. 14, 1420–1430. doi:10.1016/j.jclepro.2005.03.024

Byrne, D. (2017). Reviewing the literature. Sage Publications, Inc. https://doi.org/https://dx.doi.org/10.4135/9781526408518.

Calisto Friant, M., Vermeulen, W. J. V., & Salomone, R. (2020). A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm. Resources, Conservation and Recycling, 161(November 2019), 104917. https://doi.org/10.1016/j.resconrec.2020.104917

Camacho-Otero, J., Boks, C., & Pettersen, I. N. (2018). Consumption in the circular economy: A literature review. Sustainability (Switzerland), 10(8). https://doi.org/10.3390/su10082758

Camocho, D. J. G. (2022). Transition to circular and sustainable economy through design [Universidade Europeia]. In PhD Thesis. https://comum.rcaap.pt/handle/10400.26/41842

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. Design Studies, 47, 118–163. https://doi.org/10.1016/j.destud.2016.09.002

Ceschin, F., Vezzoli, C., Zhang, J. (Eds.) (2010). Sustainability in Design : Now! Challenges and Opportunities for Design Research, Education and Practice in the XXI Century, in: Proceedings of the LeNS Conference, Bangalore, India. 29th September to 1st October 2010. Volume II. p. 899.

Chang, D., Lee, C.K.M., Chen, C.-H. (2014). Review of Life Cycle Assessment towards Sustainable Product Development. J. Clean. Prod. 83, 48–60. doi:10.1016/j.jclepro.2014.07.050

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

Circle Economy. (2023). The Circular Gap Report 2023 (pp. 1–64). Circle Economy. https://assets.website-files.com/5e185aa4d27bcf348400ed82/63ecb3ad94e12d3e5599cf54_CGR 2023 - Report.pdf

Circle Economy. (2023). The Circular Gap Report 2023. In Deloitte. https://assets.website-files.com/5e185aa4d27bcf348400ed82/63ecb3ad94e12d3e5599cf54_CGR 2023 - Report.pdf

Coral, C., & Bokelmann, W. (2017). The role of analytical frameworks for systemic research design, explained in the analysis of drivers and dynamics of historic land-use changes. Systems, 5(1). https://doi.org/10.3390/systems5010020

Costanza, R., & Daly, H. E. (1992). Natural Capital and Sustainable Development. Conservation Biology, 6, 37–46. http://dx.doi.org/10.1046/j.1523-1739.1992.610037.x

Crisscross Furniture. Retrieved from http://www.crisscrossfurniture.com/

Crul, M.R.M., & Diehl, J.C. (Eds.), (2009). Design for sustainability - A step-by-step approach. Paris: UNEP.

Cusumano, M., Kahl S., & Suarez F. (2008), 'A theory of services in product industries', Working Paper, Cambridge, MA: MIT Sloan School.

Darian-Smith, E., & Mccarty, P. (2016). Beyond Interdisciplinarity: Developing a Global Transdisciplinary Framework. Transcience, 7(2), 26. http://www.transcience-journal.org/

De Groene Zaak, Ethica, (2015). Boosting Circular Design for a Circular Economy.

de Jesus, A., Antunes, P., Santos, R., & Mendonça, S. (2019). Eco-innovation pathways to a circular economy: Envisioning priorities through a Delphi approach. Journal of Cleaner Production, 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049

de Jesus, A., Antunes, P., Santos, R., & Mendonça, S. (2019). Eco-innovation pathways to a circular economy: Envisioning priorities through a Delphi approach. Journal of Cleaner Production, 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049

de Jesus, A., Antunes, P., Santos, R., & Mendonça, S. (2019). Eco-innovation pathways to a circular economy: Envisioning priorities through a Delphi approach. Journal of Cleaner Production, 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049

De los Rios, I.C., & Charnley, F.J.S., (2017). Skills and capabilities for a sustainable and circular economy: The changing role of design. Journal of Cleaner Production 160, 109-122. doi:10.1016/j.jclepro.2016.10.130

Demastus, J., & Landrum, N. E. (2023). Organizational sustainability schemes align with weak sustainability. Business Strategy and the Environment, December 2022, 1–19. https://doi.org/10.1002/bse.3511

Demirbilek, O., Park, M. (2001). A survey of criteria for the assessment of "Good Product Design," in: D3 Design Designium Design. The Fourth European Academy of Design Conference.

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. https://doi.org/10.1111/jiec.12610

den Hollander, M., & Bakker, C., (2012). A business model framework for product life extension. Proceedings of Sustainable Innovation 2012, Resource Efficiency, Innovation and Lifestyles, 29- 30 October 2012, Alanus University, Bonn , pp. 110-118

Design Management Institute. (n.d.). What is design management? https://www.dmi.org/page/What_is_Design_Manag

Desing, H., Brunner, D., Takacs, F., Nahrath, S., Frankenberger, K., & Hischier, R. (2020). A circular economy within the planetary boundaries: Towards a resource-based, systemic approach. Resources, Conservation and Recycling, 155(October 2019). https://doi.org/10.1016/j.resconrec.2019.104673

Diaz, A., Schöggl, J. P., Reyes, T., & Baumgartner, R. J. (2021). Sustainable product development in a circular economy: Implications for products, actors, decision-making support and lifecycle information management. Sustainable Production and Consumption, 26, 1031–1045. https://doi.org/10.1016/j.spc.2020.12.044

DRP, D.R.P.– (2017). Official definition of design [WWW Document]. URL https://designresearchportal.wordpress.com/2013/11/05/icsids-definition-of-design/ (accessed 12.9.17).

Dufresne, K. (2017). The Delphi Technique. Students 4 Best Evidence. https://s4be.cochrane.org/blog/2017/11/15/the-delphi-technique/

Dyllick, T., & Muff, K. (2016). Clarifying the Meaning of Sustainable Business: Introducing a Typology From Business-as-Usual to True Business Sustainability. Organization and Environment, 29(2), 156–174. https://doi.org/10.1177/1086026615575176

Earth Overshoot Day. (n.d.). https://www.overshootday.org/

Ekins, P., Simon, S., Deutsch, L., Folke, C., & De Groot, R. (2003). A framework for the practical application of the concepts of critical natural capital and strong sustainability. Ecological Economics, 44(2–3), 165–185. https://doi.org/10.1016/S0921-8009(02)00272-0

Ellen MacArthur Foundation (2015). Growth within: a circular economy vision for a competitive Europe. Ellen MacArthur Foundation. https://doi.org/Article

Ellen MacArthur Foundation and IDEO (2017). The Circular Design Guide. Retrieved from https://www.circulardesignguide.com/

Ellen MacArthur Foundation. (2012a). Efficiency vs Effectiveness. https://www.ellenmacarthurfoundation.org/news/efficiency-vs-effectiveness

Ellen MacArthur Foundation. (2012b). Towards the Circular Economy Vol 1: an economic and business rationale for an accelerated transition. In Ellen MacArthur Foundation (Vol. 1). https://doi.org/10.1162/108819806775545321

Ellen MacArthur Foundation; McKinsey & Company. (2015). Growth within: a circular economy vision for a competitive Europe. Ellen MacArthur Foundation, 100. https://doi.org/Article

Entrepreneur. Retrieved from (https://www.entrepreneur.com/article/81634).

Erichsen, P.G., Christensen, P.R. (2013). No Title. Creat. Innov. Manag. 22, 107–120. doi:10.1111/caim.12025

Erlandsson, J., Bergmark, P., & Höjer, M. (2023). Establishing the planetary boundaries framework in the sustainability reporting of ICT companies – A proposal for proxy indicators. Journal of Environmental Management, 329(September 2022). https://doi.org/10.1016/j.jenvman.2022.117032

European Commission. (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions - The European Green Deal. European Commission.

European Commission. (2020). Circular economy action plan. European Commission, March, 28. https://doi.org/10.2775/855540

European Commission. (2022). Green Deal: New proposals to make sustainable products the norm and boost Europe's resource independence. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_2013

European Environmental Agency. (2017). Circular by design: Products in the circular economy. EEA Report Nº 6/2017. Luxembourg: Publications Office of the European Union.

Evans, S., Partidário, P.J., Lambert, J. (2007). Industrialization as a key element of sustainable product-service solutions. Int. J. Prod. Res. 45, 4225–4246. doi:10.1080/00207540701449999

Fargnoli, M., De Minicis, M., Tronci, M. (2014). Design Management for Sustainability: An integrated approach for the development of sustainable products. J. Eng. Technol. Manag. 34, 29–45. doi:10.1016/j.jengtecman.2013.09.005

Fegade, V., Shrivatsava, R. L., & Kale, A. V. (2015). Design for Remanufacturing: Methods and their Approaches. Materials Today: Proceedings, 2(4-5), 1849-1858. https://doi.org/10.1016/j.matpr.2015.07.130

Figge, F. (2005). Capital Substitutability and Weak Sustainability Revisited: The Conditions for Capital Substitution in the Presence of Risk. Environmental Values, 14(2), 185–201.

Fink, A. (2014). Conducting Research Literature Reviews: From the Internet to Paper: From the Internet to Paper, 4th ed. SAGE Publications.

https://books.google.pt/books?hl=pt-PT&id=edTeAQAAQBAJ&q=

Fischer-Kowalski, M., Swilling, M., Weizsäcker, E. U. von, Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Kemp, R., Lankao, P. R., & Manalang, A. S. (2011). Decoupling Natural Resource Use and Environmental Impacts from Economic Growth : A Report of the Working Group on Decoupling to the International Resource Panel. In United Nations Environment Programme. https://doi.org/10.1108/03068291311305044

Fonseca, L. (2022). The EFQM 2020 model. A theoretical and critical review. Total Quality Management, 33(9-10), 1011-1038. https://10.1080/14783363.2021.1915121

Frishammar, J., & Parida, V. (2019). Circular business model transformation: A roadmap for incumbent firms. California Management Review, 61(2), 5–29. https://doi.org/10.1177/0008125618811926

Galgani, P. (2014). Reuse and design - concepts and materials, Stching Doen & Upstyle Industries.

Garcia, D. G., Kipnis, E., Vasileiou, E., & Solomon, A. (2021). Consumption in the circular economy: Learning from our mistakes. Sustainability (Switzerland), 13(2), 1–23. https://doi.org/10.3390/su13020601

Gaziulosoy, A. I. (2013). A critical review of approaches, tools and methods available for innovation teams through the perspective of sustainability science and system innovation theories. 16th ERSCP & 7th EMSU, 14.

Gaziulusoy, A. I., & Brezet, H. (2015). Design for System Innovations and Transitions: A Conceptual Framework Integrating Insights from Sustainability Science and Theories of System Innovations and Transitions. Journal of Cleaner Production, 108, 558–568. https://doi.org/10.1016/j.jclepro.2015.06.066

Gaziulusoy, A. Idil, Boyle, C., & McDowall, R. (2013). System innovation for sustainability: A systemic double-flow scenario method for companies. Journal of Cleaner Production, 45, 104–116. https://doi.org/10.1016/j.jclepro.2012.05.013

Gaziulusoy, A.I. (2015). A critical review of approaches available for design and innovation teams through the perspective of sustainability science and system innovation theories. J. Clean. Prod. 107, 366–377. doi:10.1016/j.jclepro.2015.01.012

Gaziulusoy, Ayse Idil. (2010). System Innovation for Sustainability : A Scenario Method and a Workshop Process for Product Development Teams (Vol. 1994) [The University of Auckland]. http://doi.wiley.com/10.1111/j.1468-0491.2009.01471.x

Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts—a literature analysis and redefinition. Thunderbird International Business Review, 60(5), 771–782. https://doi.org/10.1002/tie.21924

Geissdoerfer, M., Savaget, P., & Evans, S. (2017). The Cambridge Business Model Innovation Process. Procedia Manufacturing, 8, 262–269. https://doi.org/10.1016/j.promfg.2017.02.033

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geissdoerfer, M., Vladimirova, D., & Evans, S. (2018). Sustainable business model innovation: A review. Journal of Cleaner Production, 198, 401–416. https://doi.org/10.1016/j.jclepro.2018.06.240

Gerritsen, M. (2015). Circular Product Design Strategy Criteria and Guidelines. Design for Circular Economy - Demonstrator Sessions.

Ghadimi, P., Azadnia, A.H., Mohd Yusof, N., Mat Saman, M.Z. (2012). A weighted fuzzy approach for product sustainability assessment: a case study in automotive industry. J. Clean. Prod. 33, 10–21. doi:10.1016/J.JCLEPRO.2012.05.010

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gibson, R.B. (2013). Avoiding sustainability trade-offs in environmental assessment. Impact Assess. Proj. Apprais. 31, 2–12. doi:10.1080/14615517.2013.764633

Giddings, B., Hopwood, B., & O'Brien, G. (2002). Environment, economy and society: Fitting them together into sustainable development. Sustainable Development, 10(4), 187–196. https://doi.org/10.1002/sd.199

Giljum, S., Hak, T., Hinterberger, F., & Kovanda, J. (2005). Environmental governance in the European Union: Strategies and instruments for absolute decoupling. International Journal of Sustainable Development, 8(1–2), 31–46. https://doi.org/10.1504/ijsd.2005.007373

Gmelin, H., Seuring, S. (2014). Achieving sustainable new product development by integrating product life-cycle management capabilities. Int. J. Prod. Econ. 154, 166–177. doi:10.1016/j.ijpe.2014.04.023

Goedkook, M., Spriensma, R. (2001). The Eco-indicator 99: A damage oriented method for Life Cycle Impact Assessment - Methodology Report. Amesfoort.

Goodman, J., Korsunova, A., Halme, M. (2017). Our Collaborative Future: Activities and Roles of Stakeholders in Sustainability-Oriented Innovation. Bus. Strateg. Environ. 26, 731–753. doi:10.1002/bse.1941

Gorb, P. (1990). Design Management: Papers from the London Business School. Architecture Design and Technology Press.

Gordon, T. J. (1994). The Delphi Method.

Govindan, K., Azevedo, S.G., Carvalho, H., Cruz-Machado, V. (2014). Impact of supply chain management practices on sustainability. J. Clean. Prod. 85, 212–225. doi:10.1016/j.jclepro.2014.05.068

Gowdy, J. (2005). Toward a new welfare economics for sustainability. Ecological Economics, 53(2), 211–222. https://doi.org/10.1016/j.ecolecon.2004.08.007

Gray, C., & Charter, M. (2007). Remanufacturing and Product Design, Designing for the 7th Generation, The Centre for Sustainable Design, University College for the Creative Arts, Farnham, UK.

Grime, M. M., & Wright, G. (2016). Delphi Method. Wiley StatsRef: Statistics Reference Online, May, 1–6. https://doi.org/10.1002/9781118445112.stat07879

Guinée, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., Rydberg, T. (2011). Life Cycle Assessment : Past, Present and Future. Environ. Sci. Technol. 45, 90–96. doi:DOI:10.1021/es101316v

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European union and the world in 2005. Journal of Industrial Ecology, 19(5), 765–777. https://doi.org/10.1111/jiec.12244

Hahn, T., Figge, F., Pinkse, J., & Preuss, L. (2010). Editorial: Trade-offs in corporate sustainability: You can’t have your cake and eat it. Business Strategy & the Environment (John Wiley & Sons, Inc), 19, 217–229. https://doi.org/10.1002/bse.674

Hallstedt, S.I. (2017). Sustainability criteria and sustainability compliance index for decision support in product development. J. Clean. Prod. 140, 251–266. doi:10.1016/j.jclepro.2015.06.068

Hanusch, D., Birkhofer, H. (2010). Creating Socially Sustainable Products - Examinating Influence and Responsibility of Engineering Designers, in: Marjanovic, D. (Ed.), Proceedings of DESIGN 2010 - International Design Conference. Dubrovnik, pp. 771–778.

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

Hawken, P., Lovins, A.B., Lovins, L.H. (1999). Natural capitalism: Creating the next industrial revolution. Little, Brown and Co., Boston.

Hellweg, S., Benetto, E., Huijbregts, M.A.J., Verones, F. & Wood, R. 2023. Life-cycle assessment to guide solutions for the triple planetary crisis. Nature Review Earth Environment, 4(7), 471-486, https:// 10.1038/s43017-023-00449-2

Henri, J.F., Journeault, M. (2010). Eco-control: The influence of management control systems on environmental and economic performance. Accounting, Organ. Soc. 35, 63–80. doi:10.1016/j.aos.2009.02.001

Holdren, J. P., & Enrlich, P. R. (1974). Human Population and the Global Environment: Population growth, rising per capita material consumption, and disruptive technologies have made civilization a global ecological force. American Scientist, 62(3), 282–292. http://www.jstor.org/stable/27844882

Howarth, G., Hadfield, M. (2006). A sustainable product design model. Mater. Des. 27, 1128–1133. doi:10.1016/j.matdes.2005.03.016

Human Development Reports. (n.d.). https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

Iacovidou, E., Hahladakis, J. N., & Purnell, P. (2021). A systems thinking approach to understanding the challenges of achieving the circular economy. Environmental Science and Pollution Research, 28(19), 24785–24806. https://doi.org/10.1007/s11356-020-11725-9

Ijomah, W. L., McMahon, C. A., Hammond, G. P., & Newman, S. T. (2007). Development of design for remanufacturing guidelines to support sustainable manufacturing. Robotics and Computer- Integrated Manufacturing, 23(6), 712-719. https://doi.org/10.1016/j.rcim.2007.02.017.

International Electrotechnical Commission. (2019). IEC/ISO 62430: Environmental conscious design - Principles, requirements and guidance (p. 62). International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC).

ISO. (2006a). ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework, International Organization for Standardization. doi:10.1136/bmj.332.7550.1107

ISO. (2006b). ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines, International Organization for Standardization. doi:10.1136/bmj.332.7555.1418

ISO. (2010). ISO 26000:2010 Guidance on social responsibility, International Organization for Standardization. Geneva.

ISO. (2023). ISO/DIS 59004(en). Circular Economy – Terminology, Principles and Guidance for Implementation. International Organization for Standardization.

ISO. (n.d.-a). ISO/TC 207/SC 1 : Environmental management systems. https://committee.iso.org/home/tc207sc1

ISO. (n.d.-b). ISO 14001 and related standards : Environmental management. https://www.iso.org/iso-14001-environmental-management.html

Jackson, T. (2009). Prosperity without Growth: Economics for a Finite Planet. Earthscan.

Joore, P., Brezet, H. (2015). A Multilevel Design Model: The mutual relationship between product-service system development and societal change processes. J. Clean. Prod. 97, 92–105. doi:10.1016/j.jclepro.2014.06.043

Kälkäjä, R. (2016). Sustainable design strategies: Examination of aesthetics and function in zero waste and upcycling. University of Lapland, Faculty of Art and Design.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127(April), 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Klostermann, J.E.M., Tukker, A. (1998). Product Innovation and Eco-Efficiency. Kluwer Academic Publishers, Dordrecht.

Knopf, J. W. (2006). Doing a literature review. PS - Political Science and Politics, 39(1), 127–132. https://doi.org/10.1017/S1049096506060264

Koklacova, S., Valdemara, K. (2016). Design Management in the Context of Social Responsibility. J. Bus. Manag. 101–113.

Konietzko, J., Bocken, N., & Hultink, E. J. (2020). A Tool to Analyze , Ideate and Develop Circular Innovation Ecosystems. 14–17. https://doi.org/doi:10.3390/su12010417

Kootstra, G.L., 2009. The incorporation of design management in today's business practices : An analysis of design management. Inholland University of Applied Sciences, Rotterdam.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy : The Concept and its Limitations. Ecological Economics, 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Korhonen, J., Nuur, C., Feldmann, A., & Eshetu, S. (2018). Circular economy as an essentially contested concept. Journal of Cleaner Production, 175, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

Kristensen, H. S., Mosgaard, M. A., & Remmen, A. (2021). Integrating circular principles in environmental management systems. Journal of Cleaner Production, 286, 125485. https://doi.org/10.1016/j.jclepro.2020.125485

Küçüksayraç, E. (2015). Design for sustainability in companies: Strategies, drivers and needs of Turkey's best performing businesses. J. Clean. Prod. 106, 455–465. doi:10.1016/j.jclepro.2015.01.061

Lalaounis, S.T. (2017). Design Management: Organisation and Market Perspectives. Routledge, New York.

Landrum, N. E. (2018). Stages of Corporate Sustainability: Integrating the Strong Sustainability Worldview. Organization and Environment, 31(4), 287–313. https://doi.org/10.1177/1086026617717456

Landrum, N. E., & Ohsowski, B. (2018). Identifying Worldviews on Corporate Sustainability: A Content Analysis of Corporate Sustainability Reports. Business Strategy and the Environment, 27(1), 128–151. https://doi.org/10.1002/bse.1989

Lawson, B. (1997). How designers think: the design process demystified. Architectural Press.

Lefstad, L. (2021). The important role of strong sustainability and the potential of the circular economy in generating a socially and ecologically just future. Audens: Revista Estudiantil d'anàlisi Interdisciplinària, 4, 55–72.

Levandowski, C.E., Jiao, J.R., & Johannesson, H. (2015). A two-stage model of adaptable product platform for engineering-to-order configuration design engineering-to-order configuration design. Journal of Engineering Design, 2015, 26, 220-235, https://doi.org/10.1080/09544828.2015.1021305.

Lieder, M., Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51. doi:10.1016/j.jclepro.2015.12.042

Lindahl, M. (2005). Engineer Designers' requirements of design for environment methods and tools, in: Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing, 2005. Eco Design 2005. Tokyo, pp. 224–231. doi:10.1109/ECODIM.2005.1619207

Lindgreen, E. R., Salomone, R., & Reyes, T. (2020). A critical review of academic approaches, methods and tools to assess circular economy at the micro level. Sustainability (Switzerland), 12(12). https://doi.org/10.3390/su12124973

Link, S., Denz, N., Kloberdanz, H., Rath, K., Birkhofer, H., Elements, M., Affairs, E. (2013). Holistically Sustainable Products – Positive and Negative Challenges for Product Designers, in: Proceedings of EcoDesign 2013 International Symposium. doi:10.13140/RG.2.1.3090.8881

Linstone, H. A., & Turoff, M. (2002). Introduction. In H. A. Linstone & O. Turoff (Eds.), The Delphi Method : Techniques and Applications (pp. 3–12). https://doi.org/10.1007/s00256-011-1145-z

Longo, F., Padivano, A. & Umbrello, S. (2020). Value-oriented and ethical technology engineering in industry 5.0: A human-centric perspective for the design of the factory of the future. Applied Sciences (Switzerland), 10(12), 1-25. https:// 10.3390/APP10124182

Lorenz, S. (2022). Transdisciplinary sustainability research. Procedural perspectives and professional cooperation. Current Research in Environmental Sustainability, 4(June 2021), 100182. https://doi.org/10.1016/j.crsust.2022.100182

Lozano, R. (2008). Envisioning sustainability three-dimensionally. Journal of Cleaner Production, 16(17), 1838–1846. https://doi.org/10.1016/j.jclepro.2008.02.008

Luttropp, C., Lagerstedt, J. (2006). EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development. J. Clean. Prod. 14, 1396–1408. doi:10.1016/j.jclepro.2005.11.022

Mancebo, F. (2010). Le développement durable. Armand Colin. https://doi.org/doi:10.3917/arco.mance.2010.01

Manetti, G. (2011). The quality of stakeholder engagement in sustainability reporting: empirical evidence and critical points. Corp. Soc. Responsib. Environ. Manag. 18, 110–122. doi:10.1002/csr.255

Manzini, E., Collina, L., Evans, S., Buganza, T., Marchesi, A., Verganti, R., Valota, P., Rocchi, S., Lindsay, C., van der Horst, T., Meroni, A., Jégou, F., Marien, M., Vidal, L., Lambert, J., Burns, A., Luiten, H., van Sandik, E., Partidario, P., Tempelman, E., Joore, P. (2004a). Solution Oriented Partnership: How to design Industrialised Sustainable Solutions. Oscar Press, Milton Keynes.

Manzini, E., Jégou, F., Joore, P., Luiten, H., Rampino, L., Valota, P., Rocchi, S., Lindsay, C., Indekeu, E., Meroni, A., Cervetta, G., Marchesi, A., Marien, M., Vidal, L., Lambert, J., van der Horst, T. (2004b). Food delivery solutions: Cases of solution oriented partnership. Milton Keynes, U.K.

Martins, N. O. (2016). Ecosystems, strong sustainability and the classical circular economy. Ecological Economics, 129, 32–39. https://doi.org/10.1016/j.ecolecon.2016.06.003

Maxwell, D., Sheate, W., Vorst, R. Van Der, London, I.C. (2003). Sustainable Innovation in Product and Service Development, in: Towards Sustainable Product Design 8 - 8th International Conference. pp. 1–13.

Maxwell, D., van der Vorst, R. (2003). Developing sustainable products and services. J. Clean. Prod. 11, 883–895. doi:10.1016/S0959-6526(02)00164-6

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

Meadows, D. H., Meadows, D. L., Randers, J., & Beherens, W. (1972). The limits to growth : a report for the Club of Rome’s project on the predicament of mankind. Universe Books.

Melles, G., Vere, I. De, Misic, V. (2011). Socially responsible design : thinking beyond the triple bottom line to socially responsive and sustainable product design 7, 143–154.

Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2019). A methodological framework for the implementation of circular economy thinking in higher education institutions: Towards sustainable campus management. Journal of Cleaner Production, 226, 831–844. https://doi.org/10.1016/j.jclepro.2019.04.060

Mendoza, J. M. F., Sharmina, M., Gallego-Schmid, A., Heyes, G., & Azapagic, A. (2017). Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. Journal of Industrial Ecology, 21(3), 526–544. https://doi.org/10.1111/jiec.12590

Merli, R., Preziosi, M., & Acampora, A. (2018). How do scholars approach the circular economy ? A systematic literature review. Journal of Cleaner Production, 178, 703–722. https://doi.org/10.1016/j.jclepro.2017.12.112

Mestre, A., & Diehl, J.C. (2005). Ecodesign and renewable energy: How to integrate renewable energy technologies into consumer products, Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing.

Moir, S., & Carter, K. (2012). Diagrammatic representations of sustainability - A review and synthesis. Association of Researchers in Construction Management, ARCOM 2012 - Proceedings of the 28th Annual Conference, 2(September), 1479–1489.

Mont, O. (2002). Clarifying the concept of product-service system. J. Clean. Prod. 10, 237–245.

Morelli, N. (2007). Social Innovation and New Industrial Contexts: Can Designers "Industrialize" Socially Responsible Solutions? Des. Issues 23, 3–21. doi:10.1162/desi.2007.23.4.3

Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). A conceptual framework for circular design. Sustainability (Switzerland), 8(9). https://doi.org/10.3390/su8090937

Morseletto, P. (2020). Restorative and regenerative: Exploring the concepts in the circular economy. Journal of Industrial Ecology, 24(4), 763–773. https://doi.org/10.1111/jiec.12987

Moslem, S., Ghorbanzadeh, O., Blaschke, T., & Duleba, S. (2019). Analysing Stakeholder Consensus for a Sustainable Transport Development Decision by the Fuzzy AHP and Interval AHP. Sustainability, 11(12), 3271. https://doi.org/10.3390/su11123271

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. Journal of Business Ethics, 140(3), 369–380. https://doi.org/10.1007/s10551-015-2693-2

Murthy, M.A.N., Sangwan,, K.S., & Narahari, N.S. (2022). Tracing evolution of EFQM and its relationship with Industry 4.0, 33(15-16), 1737-1776. https:// 10.1080/14783363.2021.1999802

Myrdal, C.G., 2010. Integrating Environmental Considerations in Product Development Processes - Based on a Case Study at the Danish Pump Manufacturer Grundfos. Aalborg University.

Nasr, N., Russell, J., Bringezu, S., Hellweg, S., Hilton, B., Kreiss, C., & von Gries, N. (2018). Redefining Value the Manufacturing Revolution. In International Resource Panel.

Nattrass, B., Altomare, M., 1999. The Natural Step for Business: Wealth, Ecology & the Evolutionary Corporation. New Society Publishers.

Neumayer, E. (1999). Weak Versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms. Edward Elgar Publishing.

Nikolaou, I. E., & Tsagarakis, K. P. (2021). An introduction to circular economy and sustainability: Some existing lessons and future directions. Sustainable Production and Consumption, 28, 600–609. https://doi.org/10.1016/j.spc.2021.06.017

Nikolaou, I. E., Tsalis, T. A., & Evangelinos, K. I. (2019). A framework to measure corporate sustainability performance: A strong sustainability-based view of firm. Sustainable Production and Consumption, 18, 1–18. https://doi.org/10.1016/j.spc.2018.10.004

Nobre, G. C., & Tavares, E. (2021). The quest for a circular economy final definition: A scientific perspective. Journal of Cleaner Production, 314(June), 127973. https://doi.org/10.1016/j.jclepro.2021.127973

Ny, H., Hallstedt, S., Robèrt, K.H., Broman, G. (2008). Introducing templates for sustainable product development: A case study of televisions at the Matsushita Electric Group. J. Ind. Ecol. 12. doi:10.1111/j.1530-9290.2008.00061.x

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

Papanek, V. (1971). Design for the real world: Human Ecology and Social Change. Pantheon Books, New York.

Parrique, T., Barth, J., Briens, F., Kerschner, C., Kraus-Polk, A., Kuokkanen, A., & Spangenberg, J. H. (2019). Decoupling Debunked: Evidence and arguments against green growth as a sole strategy for sustainability. eeb.org/decoupling-debunked

Partidário, P.J. (2002). "What-If": From path dependency to path creation in a coatings chain. A methodology for strategies towards sustainable innovations. Technische Universiteit Delft.

Partidario, P.J., Vergragt, J. (2002). Planning of strategic innovation aimed at environmental sustainability: Actor-networks, scenario acceptance and backcasting analysis within a polymeric coating chain. Futures 34, 841–861. doi:10.1016/S0016-3287(02)00030-7

Pavlovskaia, E. (2014). Sustainability criteria: their indicators, control, and moni- toring (with examples from the biofuel sector). Environ. Sci. Eur. 26, 1e12. https://doi.org/10.1186/s12302-014-0017-2.

Pazienza, M., de Jong, M., & Schoenmaker, D. (2022). Clarifying the Concept of Corporate Sustainability and Providing Convergence for Its Definition. Sustainability (Switzerland), 14(13). https://doi.org/10.3390/su14137838

Pedersen, S., Clausen, C., & Jørgensen, M. S. (2023). Navigating value networks to co-create sustainable business models: An actionable staging approach. Business Strategy and the Environment, 32(1), 240–258. https://doi.org/10.1002/bse.3127

Pelenc, J., Ballet, J., & Dedeurwaerdere, T. (2015). Weak Sustainability versus Strong Sustainability. Brief for GSDR 2015. United Nations (UN), 2005, 1–4. https://sustainabledevelopment.un.org/content/documents/6569122-Pelenc-Weak Sustainability versus Strong Sustainability.pdf

Petala, E., Wever, R., Dutilh, C., Brezet, H. (2010). The role of new product development briefs in implementing sustainability: A case study. J. Eng. Technol. Manag. 27, 172–182. doi:10.1016/J.JENGTECMAN.2010.06.004

Pieroni, M. P. P., Mcaloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability : A review of approaches. Journal of Cleaner Production, 215, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

Pigosso, D. C. A., & McAloone, T. C. (2021). Making the transition to a Circular Economy within manufacturing companies: the development and implementation of a self-assessment readiness tool. Sustainable Production and Consumption, 28, 346–358. https://doi.org/10.1016/j.spc.2021.05.011

Pigosso, D. C. A., Rozenfeld, H., McAloone, T.C. (2013). Ecodesign maturity model: a management framework to support ecodesign implementation into manufacturing companies. J. Clean. Prod. 59, 160–173. doi:10.1016/j.jclepro.2013.06.040

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in the product chain - Policy report. PBL Netherlands Environmental Assessment Agency, January, PBL publication number 2544.

Prendeville, S., Niemczyk, M., Sanders, C., Lafond, E., Elgorriaga, A., Mayer, S., Kane, D. (2013). Motivations for and Barriers to Ecodesign in Industry.

Prieto-Sandoval, V., Jaca, C., & Ormazabal, M. (2018). Towards a consensus on the circular economy. Journal of Cleaner Production, 179, 605–615. https://doi.org/10.1016/j.jclepro.2017.12.224

Prieto-Sandoval, V., Jaca, C., & Ormazabal, M. (2018). Towards a consensus on the circular economy. Journal of Cleaner Production, 179, 605–615. https://doi.org/10.1016/j.jclepro.2017.12.224

Quarshie, A.M., Salmi, A., Leuschner, R. (2016). Sustainability and corporate social responsibility in supply chains: The state of research in supply chain management and business ethics journals. J. Purch. Supply Manag. 22, 82–97. doi:10.1016/j.pursup.2015.11.001

Raworth, K. (2017). A Doughnut for the Anthropocene: humanity's compass in the 21st century. The Lancet Planetary Health, 1(2), e48–e49. https://doi.org/10.1016/S2542-5196(17)30028-1

Raworth, K. (2017). Doughnut economics : seven ways to think like a 21st-century economist. Random House.

Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling, 135(November 2017), 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Richardson, J., Irwin, T., Sherwin, C., 2005. Design & Sustainability: A Scoping Report for the Sustainable Design Forum.

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kummu, M., Mohan, C., Nogués-Bravo, D., … Rockström, J. (2023). Earth beyond six of nine planetary boundaries. Science Advances, 9(37). https://doi.org/10.1126/sciadv.adh2458

Robèrt, K.-H. (2000). Tools and concepts for sustainable development, how do they relate to a general framework for sustainable development, and to each other? J. Clean. Prod. 8, 243–254. doi:10.1016/S0959-6526(00)00011-1

Robèrt, K.-H., Schmidt-Bleek, B., Aloisi de Larderel, J., Basile, G., Jansen, J.L., Kuehr, R., Prive Thomas, P., Suzuki, M., Hawken, P., Wackernagel, M. (2002). Strategic sustainable development — selection, design and synergies of applied tools. J. Clean. Prod. 10, 197–214.

Rocha, C. S., Antunes, P., & Partidário, P. (2019). Design for sustainability models: A multiperspective review. In Journal of Cleaner Production (Vol. 234, pp. 1428–1445). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2019.06.108

Rocha, C. S., Camocho, D., & Alexandre, J. (2020). Design and development. In C. S. Rocha, D. Camocho, J. Sampaio, & J. Alexandre (Eds.), Product-Service Development for Circular Economy and Sustainability Course (pp. 238–293). LNEG - Laboratório Nacional de Energia e Geologia, I.P.

Rocha, C., Brezet, H. (1999). Product-oriented Environmental Management Systems: A Case Study. J. Sustain. Prod. Des. 10, 30–42.

Rocha, C., Schmidt, K. (2014). The ISO 26000 standard as a driver for systemic Design for Sustainability, in: The Europe We Want: 17th European Roundtable on Sustainable Consumption and Production - ERSCP 2014. Portoroz, pp. 108–129. doi:978-961-93738-1-1

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., … Foley, J. (2009). Planetary boundaries: Exploring the safe operating space for humanity. Ecology and Society, 14(2). https://doi.org/10.5751/ES-03180-140232

Rossi, M.S., Brown, H.S., Baas, L.W. (2000). Leaders in sustainable development: how agents of change define the agenda. Bus. Strateg. Environ. (John Wiley Sons, Inc) 9, 273–286. doi:10.1002/1099-0836(200009/10)9:5<273::AID-BSE254>3.0.CO;2-Q

RSA. (2016). Designing for a circular economy: Lessons from The Great Recovery 2012 – 2016. In RSA Action and Research Centre (Issue March). http://www.greatrecovery.org.uk/resources/new-report-lessons-from-the-great-recovery-2012-2016/

Salari, M., Bhuiyan, N. (2016). A proposed approach to improve current sustainable product development. J. Ind. Prod. Eng. 33, 297–307. doi:10.1080/21681015.2016.1172122

Sanders, E.B.-N., Stappers, P.J. (2008). Co-creation and the new landscapes of design. CoDesign Int. J. CoCreation Des. Arts 4, 5–18. doi:10.1080/15710880701875068

Sartorius, C. (2006). Second-order sustainability—conditions for the development of sustainable innovations in a dynamic environment. Ecological Economics, 58(2), 268–286.

Sauvé, S., Bernard, S., & Sloan, P. (2016). Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. Environmental Development, 17, 48–56. https://doi.org/10.1016/j.envdev.2015.09.002

Schaltegger, S., Hansen, E. G., & Lüdeke-Freund, F. (2016). Business Models for Sustainability: Origins, Present Research, and Future Avenues. Organization and Environment, 29(1), 3–10. https://doi.org/10.1177/1086026615599806

Schifferstein, H. N., & Zwartkruis-Pelgrim, E. P. (2008). Consumer-product attachment: Measurement and design implications. International Journal of Design, 2(3).

Schmidheiny, S. (1992). Changing Course: A Global Business Perspective on Development and the Environment. MIT Press.

Schmidt, K., Bundgaard, A., Hirsbak, S., Rocha, C. S., Camocho, D., & Alexandre, J. (2020). Introduction to the circular economy. In C. S. Rocha, D. Camocho, J. Sampaio, & J. Alexandre (Eds.), Product-Service Development for Circular Economy and Sustainability Course (pp. 2–71). LNEG - Laboratório Nacional de Energia e Geologia, I.P.

Schröder, P., Bengtsson, M., Cohen, M., Dewick, P., Hoffstetter, J., & Sarkis, J. (2019). Degrowth within – Aligning circular economy and strong sustainability narratives. In Resources, Conservation and Recycling (Vol. 146, pp. 190–191). Elsevier B.V. https://doi.org/10.1016/j.resconrec.2019.03.038

Schroeder, P. (2018). The Relevance of Circular Economy Practices to the Sustainable Development Goals. 23(1), 77–95. https://doi.org/10.1111/jiec.12732

Spangenberg, J.H., Fuad-Luke, A., Blincoe, K. (2010). Design for Sustainability (DfS): the interface of sustainable production and consumption. J. Clean. Prod. 18, 1485–1493. doi:10.1016/j.jclepro.2010.06.002

Stahel W.R. (1998). Product Durability and Re-Take after Use. In: Kostecki M. (eds) The Durable Use of Consumer Products. Springer, Boston, MA DOI https://doi.org/10.1007/978-1-4757-2819-4_2

Stahel, W.R. (2010). The Performance Economy, 1st ed.; Palgrave Macmillan: Hampshire, UK.

Stahel, W.R. (2016). The circular economy. Nature 531. doi:10.1038/531435a

Staples, L. (2008). Design Management, in: Erlhof, M., Marshall, T. (Eds.), Design Dictionary: Perspectives on Design Terminology. Birkhäuser Basel, pp. 119–121. doi:10.1007/978-3-7643-8140-0_84

Starik, M., & Kanashiro, P. (2013). Toward a Theory of Sustainability Management: Uncovering and Integrating the Nearly Obvious. Organization and Environment, 26(1), 7–30. https://doi.org/10.1177/1086026612474958

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223). https://doi.org/10.1126/science.1259855

Stevels, A.L.N. (2009). Adventures in EcoDesign of Electronic Products: 1993-2007. A personal vision. Delft University of Technology, Design for Sustainability Program Publication nr. 17, Delft.

Sumter, D. X., Bakker, C. A., & Balkenende, A. R. (2017). The role of product designers in the transition towards the Circular Economy : A Reality Check . Product Lifetimes and The Environment Conference, November, 8. https://doi.org/10.3233/978-1-61499-820-4-391

Tao, J., Yu, S. (2018). Product life cycle design for sustainable value creation: methods of sustainable product development in the context of high value engineering, in: Procedia CIRP. pp. 25–30. doi:10.1016/j.procir.2017.11.099

Thrane, M., Eagan, P. (2007). Ecodesign, in: Kørnøv, L., Thrane, Mikkel, Remmen, A., Lund, H. (Eds.), Tools for Sustainable Development. Narayana Press, Aalborg Universitetsforlag, pp. 267–291.

Tischner, U. (2008). Design for (social) sustainability and radical change, in: Tukker, A., Charter, M., Vezzoli, C., Sto, E., Andersen, M.M. (Eds.), System Innovation for Sustainability 1: Perspectives on Radical Changes to Sustainable Consumption and Production. Greenleaf Publishing Limited, Sheffield, pp. 159–177.

Tischner, U., Ryan, C., Vezzoli, C. (2009). Product-Service Systems, in: Crul, M., Diehl, J.C. (Eds.), Design for Sustainability: A Step by Step Approach. UNEP, Paris, pp. 95–101.

Tischner, U., Schmincke, E., Rubik, F., Prösler, M., 2000. How to do ecodesign? A guide for environmental and economically sound design. Art Books International Limited, Berlin.

Tischner, U., Tukker, A. (2006). A practical guide for PSS development, in: Tukker, A., Tischner, U. (Eds.), New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability. Greenleaf Publishing Limited, Sheffield, pp. 375–393.

Tischner, U., Vezzoli, C. (2009). Product-Service Systems: Tools and Cases, in: Design for Sustainability: A Step-by-Step Approach - Modules. pp. 33–75.

Totaro, A. I. (2023). The Netherlands, Circular by Design. Renewable Matter, 44.

Tukker, A. (2004). Eight Types of Product-Service Systems. Business Strategy and the Environment, 13, 246-260. https://doi.org/10.1002/bse.414

Tukker, A. (2008). Sustainability: a multi-interpretable notion, in: Tukker, A., Charter, M., Vezzoli, C., Sto, E., Andersen, M.M. (Eds.), System Innovation for Sustainability 1: Perspectives on Radical Changes to Sustainable Consumption and Production. Greenleaf Publishing Limited, Sheffield, pp. 14–43.

Tukker, A. (2015). Product services for a resource-efficient and circular economy - A review. Journal of Cleaner Production, 97, 76–91. https://doi.org/10.1016/j.jclepro.2013.11.049

Tukker, A., Tischner, U. (2006). New Business for Old Europe: Product-Service Development, Competitiveness and Sustainability. Greenleaf Publishing, Shefield.

Tukker, A., van den Berg, C., & Tischner, U. (2006). Product-services: a specific value proposition. In A. Tukker & U. Tischner (Eds.), New Business for Old Europe: product-service development, competitiveness and sustainability (pp. 22-34). Sheffield: Greenleaf Publishing Limited.

Ulrich, K., Eppinger, S. (2000). Product Design and Development, 2nd edition. ed. McGraw-Hill.

UN General Assembly. (2015). Transforming our world : the 2030 Agenda for Sustainable Development. https://www.refworld.org/docid/57b6e3e44.html

UNEP. (2012). Environment for the future we want. In Population and Development Review (Vol. 24). https://doi.org/10.2307/2807995

United Nations. (2017a). United Nations Millennium Development Goals [WWW Document]. URL http://www.un.org/millenniumgoals/ (accessed 12.9.17).

United Nations. (2017b). Sustainable Development Goals: 17 Goals to Transform Our World [WWW Document]. URL http://www.un.org/sustainabledevelopment/ (accessed 12.9.17).

van Bommel, H.W.M. (2011). A conceptual framework for analyzing sustainability strategies in industrial supply networks from an innovation perspective. J. Clean. Prod. 19, 895–904. doi:10.1016/j.jclepro.2010.12.015

van den Berg, M.R. & Bakker, C. (2015). A product design framework for a circular economy. PLATE - Product Lifetimes and the Environment Conference. Nottingham Trent University, 17-19 June. 365-379.

van der Heijden, A., Cramer, J.M. (2017). Change agents and sustainable supply chain collaboration: A longitudinal study in the Dutch pig farming sector from a sensemaking perspective. J. Clean. Prod. 166, 967–987. doi:10.1016/j.jclepro.2017.08.074

Van Der Heijden, A., Driessen, P.P.J., Cramer, J.M., 2010. Making sense of Corporate Social Responsibility: Exploring organizational processes and strategies. J. Clean. Prod. 18, 1787–1796. doi:10.1016/j.jclepro.2010.07.024

van Hemel, C., 1998. Ecodesign empirically explored: Design for environment in Dutch small and medium sized enterprises. Delft University of Technology.

van Os, P. (2023). O programa CIRCO internacional. LNEG - Laboratório Nacional de Energia e Geologia, I.P. https://circohubportugal.lneg.pt/

van Weenen, J.C., 1995. Towards sustainable product development. J. Clean. Prod. 3, 95–100.

Vasantha, G.G.V.A., Roy, R., Taylor, P., Vijaykumar, G., Vasantha, A., Roy, R., Brissaud, D., Vasantha, G.G.V.A., Roy, R., Lelah, A., Brissaud, D., 2012. A review of product – service systems design methodologies. J. Eng. Des. 23, 635–659. doi:10.1080/09544828.2011.639712

Vazquez, D., Bruce, M., 2002. Design management – the unexplored retail marketing competence. Int. J. Retail Distrib. Manag. 30, 202–210. doi:10.1108/09590550210423672

Velenturf, A. P. M., & Purnell, P. (2021). Principles for a sustainable circular economy. Sustainable Production and Consumption, 27, 1437–1457. https://doi.org/10.1016/j.spc.2021.02.018

Vezzoli, C., Ceschin, F. (2011). The Learning Network on Sustainability: an e-mechanism for the development and diffusion of teaching materials and tools on Design for Sustainability in an open-source and copy left ethos. Int. J. Manag. Educ. 5, 22–43. doi:10.1504/IJMIE.2011.037753

Vezzoli, C., Manzini, E. (2008a). Evolution of Sustainability in Design Research and Practice, in: Design for Environmental Sustainability. Springer London, pp. 253–262. doi:10.1007/978-1-84800-163-3_14

Vezzoli, C., Manzini, E. (2008b). Review: design for sustainable consumption and production systems, in: Tukker, A., Charter, M., Vezzoli, C., Sto, E., Andersen, M.M. (Eds.), System Innovation for Sustainability 1: Perspectives on Radical Changes to Sustainable Consumption and Production. Greenleaf Publishing Limited, Sheffield, pp. 138–158.

Vicente, J., Frazão, R., Rocha, C., Silva, F.M. da (2010). The integration of social criteria in sustainable design for furniture, in: Knowledge Collaboration & Learning for Sustainable Innovation: 14th European Roundtable on Sustainable Consumption and Production (ERSCP) Conference and the 6th Environmental Management for Sustainable Universities (EMSU) Conference. Delft University of Technology, Delft.

Vila, C., Abellán-Nebot, J. V., Albiñana, J.C., Hernández, G., 2015. An Approach to Sustainable Product Lifecycle Management (Green PLM). Procedia Eng. 132, 585–592. doi:10.1016/j.proeng.2015.12.608

Visser, W. (2011). The ages and stages of CSR: Towards the Future with CSR 2.0. CSR International Paper Series. http://www.waynevisser.com/wp-content/uploads/2012/05/paper_ages_stages_csr_wvisser.pdf

Visser, W. (2012). The Future of CSR: Towards Transformative CSR , or CSR 2 . 0. SSRN. https://doi.org/http://dx.doi.org/10.2139/ssrn.2208101

von Weizsacker, E., Lovins, A., & Lovins, L. (1998). Factor Four: Doubling Wealth, Halving Resource Use. A Report to the Club of Rome. Earthscan Publications Ltd.

Waage, S. A. (2007). Re-considering product design: a practical "road-map" for integration of sustainability issues. J. Clean. Prod. 15, 638–649. doi:10.1016/j.jclepro.2005.11.026

Watkins, M.A. (2014). An investigation into effective methods for teaching social sustainability within product design in British and Irish Universities. Loughborough University.

WCED. (1987). Our Common Future: Report of the World Commission on Environment and Development. In United Nations World Commission on Environment and Development (Vol. 4, Issue 1). https://doi.org/10.1080/07488008808408783

Weizsäcker, E., de Larderel, J., Hargroves, K., Hudson, C., Smith, M., & Rodrigues, M. (2014). Decoupling 2 Technologies, Opportunities and Policy Options. In UNEP.

Wimmer, W., Zust, R., 2001. ECODESIGN PILOT - Developing a Product Innovation Learning and Optimization Tool For Sustainable Product Development With Cd-Rom, 1st edition. ed. Kluwer Academic Publishers, Dordrecht.

Wise, R., & Baumgartner, P., (1999). Go Downstream e the new profit Imperative in manufacturing. In: Harvard Business Review 77

Wójcik, P., 2018. The business case for corporate social responsibility: A literature overview and integrative framework. J. Manag. Bus. Adm. Cent. Eur. 26, 121–148. doi:10.7206/jmba.ce.2450-7814.222

Wynn, D.C., Clarkson, P.J., 2017. Process models in design and development. Res. Eng. Des. 1–42. doi:10.1007/s00163-017-0262-7

Zhang, J., Xue, D., & Gu, P., (2015). An Integrated Framework to Design Architecture, Configurations and Parameters of Adaptable Product with Robust Performance. CIRP 25th Design Conference Innovative Product Creation, Procedia CIRP. 36:147-152 DOI: 10.1016/j.procir.2015.01.077

A

APPENDIX A

Features of circular economy definitions found in the literature, relevant for chapter 5.

Features	Sources
Overarching objectives:	
A contribution to sustainable development	(de Jesus et al., 2019; Desing et al., 2020; Kirchherr et al., 2017; Korhonen et al., 2018; Prieto-Sandoval et al., 2018; Schmidt et al., 2020);
Environmental sustainability: a model to operate within the planet boundaries, to reach environmental objectives, to support ecosystem functioning	(de Jesus et al., 2019; Desing et al., 2020; Kirchherr et al., 2017; Korhonen et al., 2018; Prieto-Sandoval et al., 2018; Schmidt et al., 2020);
Social sustainability: promoting social objectives, social equity, well-being	(de Jesus et al., 2019; Desing et al., 2020; Kirchherr et al., 2017; Schmidt et al., 2020);
Economic sustainability: long-term economic prosperity, economic objectives	(de Jesus et al., 2019; Desing et al., 2020; Kirchherr et al., 2017);
Identification of CE strategies:	
Closing resource loops/cycles, elimination of the end-of-life concept, waste minimization/prevention, avoiding resources depletion	(Alhawari et al., 2021; de Jesus et al., 2019; Desing et al., 2020b; Geisendorf & Pietrulla, 2018; Kirchherr et al., 2017; Korhonen et al., 2018; Nobre & Tavares, 2021; Prieto-Sandoval et al., 2018; Schmidt et al., 2020)
Slowing resource loops, maintaining products and materials for the longest possible time	(Desing et al., 2020; Geisendorf & Pietrulla, 2018; Schmidt et al., 2020);
Narrowing resource loops, promoting efficiency	(Alhawari et al., 2021; de Jesus et al., 2019; Desing et al., 2020b; Nobre & Tavares, 2021; Schmidt et al., 2020)
Distinction between the resources that flow in biological cycles/renewable resources/regeneration[10] and those that flow in technological cycles/non-renewable resources/restoration[11]	(Desing et al., 2020; Nobre & Tavares, 2021; Schmidt et al., 2020);

[10] In the context of CE, regeneration is "the promotion of self-renewal capacity of natural systems"(Morseletto, 2020, p.769).

[11] In the context of CE, restoration is "the return to a previous or original state"(Morseletto, 2020, p.769).

Features	Sources
Indication and eventually prioritization of "R" circularity strategies such as reduce, reuse, repair, recover, recycling	(de Jesus et al., 2019; Kirchherr et al., 2017);
Extracting/capturing/maintaining the value of products and materials	(Geisendorf & Pietrulla, 2018; Korhonen, Honkasalo, et al., 2018; Schmidt et al., 2020);
Addressing energy: a system powered by renewable energy, energy efficiency	(Desing et al., 2020; Korhonen et al., 2018; Nobre & Tavares, 2021; Prieto-Sandoval et al., 2018; Schmidt et al., 2020);
Identification of enablers:	
Design of products and systems for circularity	(de Jesus et al., 2019; Geisendorf & Pietrulla, 2018; Schmidt et al., 2020);
Business models innovation	(Desing et al., 2020; Kirchherr et al., 2017; Schmidt et al., 2020);
Technological innovation	(Desing et al., 2020; Kirchherr et al., 2017);
Organizational planning processes	(Alhawari et al., 2021)
Not only production, but also consumption	(Kirchherr et al., 2017; Korhonen et al., 2018; Nobre & Tavares, 2021; Prieto-Sandoval et al., 2018; Schmidt et al., 2020)
Indication of different scales to which CE applies:	
Micro (product, service, organization), meso (agents in industrial parks, industrial symbiosis) and macro (city, region, nation and beyond)	(Geisendorf & Pietrulla, 2018; Kirchherr et al., 2017; Nobre & Tavares, 2021; Prieto-Sandoval et al., 2018).

B

APPENDIX B

Circular design strategies to close, slow, narrow and regenerate resource flows at product, business model and ecosystem levels relevant for chapter 5 (based on Bocken et al., 2016; Konietzko et al., 2020; Rocha et al., 2020).

Design strategies to close resource loops		
At product level	**At business model level**	**At ecosystem level**
Design with materials suitable for primary recycling (technological and biological cycles) (Bocken et al., 2016; Konietzko et al., 2020; Rocha et al., 2020).	Enable and incentivize product and component returns (Konietzko et al., 2020).	Organize local waste-to-product ecosystems (Konietzko et al., 2020).
Design for dis- and reassembly (Bocken et al., 2016).	Extending resource value (Bocken et al., 2016).	
Design for remanufacturing (Rocha et al., 2020)	Industrial symbiosis (Bocken et al., 2016).	
Design strategies to slow resource loops		
At product level	**At business model level**	**At ecosystem level**
Design long-life products (attachment and trust; reliability and durability; upgradability and adaptability; repairability; user-friendliness) (Bocken et al., 2016; Konietzko et al., 2020; Rocha et al., 2020).	Offer the product as a service, access and performance models (Bocken et al., 2016; Konietzko et al., 2020; Rocha et al., 2020).	Turn disposables into a reusable service (Konietzko et al., 2020).
	Extending product value (e.g., repair, maintenance, upgrade services (Bocken et al., 2016).	
	Classic long-life model (Bocken et al., 2016).	

	Encourage sufficiency (Bocken et al., 2016).	
Design strategies to narrow resource loops		
At product level	**At business model level**	**At ecosystem level**
Design with low impact inputs (Konietzko et al., 2020; Rocha et al., 2020).	Incentivize users to consume less[(1)] (Konietzko et al., 2020).	Maximize the usage capacity of products (Konietzko et al., 2020).
Design for sustainable consumer behaviour in the use phase (Rocha et al., 2020)		
Design for energy sustainability (reduce energy consumption along the life cycle, use low embodied energy materials, influence consumer behaviour regarding energy consumption) (Rocha et al., 2020)		
Design strategies to regenerate resource loops		
At product level	**At business model level**	**At ecosystem level**
Design with non-toxic, renewable materials (Konietzko et al., 2020).	Produce with renewable energy (Konietzko et al., 2020).	Recover nutrients from urban areas (Konietzko et al., 2020).

C

APPENDIX C

Overview of existing CE frameworks to support companies in the transition towards CE, relevant for chapter 5.

Framework and reference	What	How and focus	Contribution
Rounding the vertices – Design for the Circular Economy toolkit (Camocho, 2022)	Toolkit for circular design, which aims to guide the project helping in its definition and planning, in identifying options for improvement and identifying ideas to develop new solutions. It also allows validating and demonstrating the performance of circularity of the design process carried out and its results.	How: This resource is composed of four tools that complement each other, namely the Project definition worksheet, the Project planning worksheet, the Circular Design Mbox and the Circularity Assessment Tool. Focus: designers and professionals directly involved with the development of products and services.	An action-oriented model with three distinct layers that are interconnected resulting in a holistic approach. This comprises 1) a layer related to the development of the business, integrating the needs to create wealth and value in the strategy of the business, 2) a layer related to project management, acting in the transposition of the identified needs for the companies and the needs of the customers/users, and 3) an operational layer, linked to the

Framework and reference	What	How and focus	Contribution
			practical development of the design project.
MATChE (MAking the Transition to a Circular Economy) (Pigosso & McAloone, 2021)	A CE readiness self-assessment tool that supports companies in: (i) understanding strengths and gaps for CE implementation; (ii) performing internal and external benchmarking; (iii) prioritising focus areas; and (iv) planning transition paths with support of CE-related tools, methods and approaches.	How: The MATChE tool supports a ten-step approach for the transition toward a CE focusing on eight dimensions: (1) Organisation; (2) Strategy and Business Model Innovation; (3) Product & Service Innovation; (4) Manufacturing & Value Chain; (5) Technology & Data; (6) Use, Support & Maintenance; (7) Takeback & End-of-Life Strategies; and (8) Policy & Market. Focus: organizations	Addressing the lack of analytical diagnostic tools and an understanding of the readiness of companies to migrate from a linear to a circular model, which partly explains limited implementation of CE and a higher chance of failure during implementation.
Circularity deck (Konietzko et al., 2020)	Tool to facilitate companies to take an ecosystem perspective on circular-oriented innovation.	How: 3-hours sessions using a deck of cards containing product, business model and ecosystem innovation principles that can narrow, slow, regenerate and inform materials and energy flows in a given context, and to analyse which actors are needed to do so. Focus: products, business models and ecosystems	Existing approaches do not differentiate a business model perspective from an ecosystem perspective, which is necessary since CE is a systemic concept. This tool enables participants to analyse, ideate and develop the circularity potential of their innovation ecosystems.
Circular Strategies Scanner (Blomsma et al., 2019)	The Circular Strategies Scanner provides a comprehensive set of definitions of circular strategies and directly supports the early stages of	How: Workshops using the Scanner to support visioning in COI processes, through supporting the explication of CE, mapping current CE initiatives, and generating ideas for increased circularity.	Previous work focuses on answering “what” or “how” to promote COI. There is a lack in supporting the early stages of COI through the establishment of a

Framework and reference	What	How and focus	Contribution
	circular oriented innovation (COI).	Focus: organizations	CE vision, i.e., answering "why" to perform COI.
A methodological framework for the implementation of circular economy thinking in higher education institutions (HEI's) (Mendoza et al., 2019)	A framework and guidance to help universities develop a circular economy strategy aimed at improving resource efficiency and environmental sustainability of their campus operations, compatible with broader sustainability management frameworks used by HEI's.	How: 3 main steps: A) background analysis of the congruence of existing sustainability policies with CE principles; B) foreground analysis (stakeholder engagement); and C) implementation of a CE strategy (guidelines for action: Plan-Do-Check-Act). Focus: organizations	To address a lack of knowledge on how to implement CE principles to sustainable campus management.
Roadmap for Circular Business Model Transformation (Frishammar & Parida, 2019)	A step-by-step process to enable circular transition through circular business model transformation, allowing companies to meet environmental, social, and financial objectives and proactively address sustainability.	How: Iterative process following four phases: (1) Initiation: mapping and understanding the CE transformation requirements; (2) Audit: the current business model made explicit, including shortcomings, opportunities, and scope for circular transformation; (3) Design and development of a circular business model based on the ReSOLVE framework, including benchmarking, internal alignment and configuring ecosystem partners; (4) Scaling up, after a small-scale pilot testing. Focus: business models	Depicting a detailed circular business model transformation process, which is missing from the PSS literature, and overcoming the prevailing focus on a single firm's business model by highlighting the influence of ecosystem actors.

Framework and reference	What	How and focus	Contribution
BECE (backcasting and eco-design for the circular economy) framework (Mendoza et al., 2017)	BECE empowers organizations to tackle the CE holistically by embedding the concept into corporate decision making and by bringing operational and systems thinking together, thus increasing the likelihood of successful implementation.	How: Ten steps, created by combining the relevant steps from backcasting and eco-design. Focus: organizations	Combining backcasting and eco-design, as approaches, i.e., taking a top-down and bottom-up strategic approach required to support a successful realization of the CE concept, jointly supported by relevant stakeholders.
BS 8001:2017 - Framework for implementing the principles of the circular economy in organizations – Guide (British Standards Institute, 2017)	BS 8001:2017 is intended to help organizations and individuals consider and implement more circular and sustainable practices within their businesses, whether through improved ways of working, providing more circular products and services or redesigning their entire business model and value proposition.	How: The standard is divided into two areas: 1) Helping organizations improve their understanding of the CE and how it might be relevant. 2) Support in implementation of the principles of the CE within an organizational context. Focus: organizations	BS 8001:2017 is the first standard of its kind for organizations to implement the principles of the CE and is useful to those with varying levels of knowledge and understanding of the CE. It provides practical ways to secure smaller ‘quick-wins’, right through to helping organizations rethink holistically how their resources are managed to enhance financial, environmental and social benefits.

D

Appendix D

Delphi questionnaire – 1st round, relevant for chapter 5.

Design for the circular economy and strong sustainability:
towards an implementation model
Experts' consultation using the Delphi method

0. Profile of the respondent

Name:

Preferred e-mail:

Country:

Type of organisation:

- ☐ Academia
- ☐ Business
- ☐ Public administration
- ☐ NGO

Please indicate your main fields of expertise. You can select multiple options.

- ☐ Environmental/Sustainability Management of Organisations
- ☐ Design for Sustainability/Circular Design
- ☐ Circular Economy
- ☐ Ecological Economics
- ☐ Organisational Social responsibility
- ☐ Environmental/Sustainability Policy

- ☐ Other

If you chose “other”, please specify:

1. Definition of design for the circular economy and strong sustainability

Our working definition of design for the circular economy and strong sustainability is as follows:

Design of products, product-service systems, and business models that create positive environmental, social and economic value and contribute to a society operating within the planetary boundaries, while promoting social well-being and equity.
This is accomplished through closing, narrowing, slowing and regenerating resource flows in production, distribution and consumption processes, extracting the highest value and usefulness of materials, equipment and goods, for the longest possible time, in cycles energized by renewable or otherwise sustainable energy sources, with a systemic view.

1.1 To what extent do you agree with this definition?

- ☐ Strongly agree
- ☐ Agree
- ☐ Undecided
- ☐ Disagree
- ☐ Strongly disagree

1.1.1 Please justify your answer

2. Circular economy and strong sustainability

2.1 In your opinion, which are the features of circular economy and strong sustainability that are aligned?

2.2 In your opinion, which are the features of circular economy and strong sustainability that are conflicting?

3. Contributions of the model

3.1 Which are the most important contributions that an implementation model can make to the development of products, product-service systems, and business models that effectively contribute to circular economy and strong sustainability?

3.2 Do you have any recommendations for the model to attain such effectiveness?

4. Elements of the model

Considering:

– Your understanding of design for the circular economy and strong sustainability at organizations' level, and

– A proposed structure and contents of the model, with elements on the strategic, tactical and operational levels (figure 1),

please answer the questions 4.1 to 4.11.

Figure 1
Suggested elements of a
design for circular economy and strong sustainability implementation model

Elements on the strategic level: overall policies, missions and agendas	**1.** Establishment of a vision for circular economy and strong sustainability to which the company contributes
	2. Alignment of the business strategy with the vision
	3. Stakeholder involvement in establishing the vision, co-development of circular and sustainable solutions, and sustainability assessment
Elements on the tactical level: teams, processes and systems of specific business units or functions	**4.** Circular and sustainable design strategies and criteria covering environmental, social and economic dimensions
	5. Sustainability and circularity assessment with a life cycle perspective
	6. Integration of design for circular economy and strong sustainability in management systems and practices (environment, quality, social responsibility, others)
	7. Involvement of different internal functions within a company in the design process
Elements on the operational level: tasks relevant to the completion of individual projects and how they are organized	**8.** Organization of the design and development process for products, product-service systems and business models

Questions 4.1 to 4.3 concern the strategic level.

4.1 Please rate the importance of element 1. Establishment of a vision for circular economy and strong sustainability to which the company contributes (strategic):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.1.1 Please justify and/or comment.

4.2 Please rate the importance of element 2. Alignment of the business strategy with the vision (strategic):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.2.1 Please justify and/or comment.

4.3 Please rate the importance of element 3. Stakeholder involvement in establishing the vision, co-development of circular and sustainable solutions, and sustainability assessment (strategic):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important

- ☐ Unimportant

4.3.1. Please justify and/or comment.

Questions 4.4 to 4.7 concern the tactical level.

4.4 Please rate the importance of element 4. Circular and sustainable design strategies and criteria covering environmental, social and economic dimensions (tactical):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.4.1. Please justify and/or comment.

4.5 Please rate the importance of element 5. Sustainability and circularity assessment with a life cycle perspective (tactical):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.5.1. Please justify and/or comment.

4.6 Please rate the importance of element 6. Integration of design for circular economy and strong sustainability in management systems and practices (environment, quality, social responsibility, others) (tactical):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.6.1. Please justify and/or comment.

4.7 Please rate the importance of element 7. Involvement of different internal functions within a company in the design process (tactical):

- ☐ Very important
- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.7.1. Please justify and/or comment.

Question 4.8 concerns the operational level.

4.8 Please rate the importance of element 8. Organization of the design and development process for products, product-service systems and business models (operational):

- ☐ Very important

- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

4.8.1. Please justify and/or comment.

4.9 Please indicate any important missing element in a design for the circular economy and strong sustainability implementation model, at the strategic level.

4.10 Please indicate any important missing element in a design for the circular economy and strong sustainability implementation model, at the tactical level.

4.11 Please indicate any important missing element in a design for the circular economy and strong sustainability implementation model, at the operational level.

This survey ends here. Thank you very much for your time!
cristina.rocha@lneg.pt

E

APPENDIX E

Delphi questionnaire – 2nd round, relevant for chapter 5.

A model of design for a circular economy in a strong sustainability paradigm

0. Profile of the respondent

Name:

Preferred e-mail:

1. Definition

We are very grateful for all the comments that we have received for the previous definition of "design for circular economy and string sustainability". We tried to properly address all of them, including rephrasing the concept. The new definition of "design for a circular economy in a strong sustainability paradigm" reads as follows:

Design of products, product-service systems, and business models and production-consumption systems that contribute to a society that thrives within the planetary boundaries, while stimulating social well-being and equity.

This is accomplished through:

- Closing, narrowing and slowing resource flows and regenerating natural systems in production, distribution, consumption and post-consumption processes, in cycles energized by renewable sources;
- Retaining and creating the highest value and usefulness of materials, equipment and goods for the longest possible time, preferably at the local human scale;
- Contributing to a social foundation of wellbeing derived from stakeholders' needs and expectations and internationally agreed social standards.

1.1 To what extent do you agree with this definition?

☐ Strongly agree

☐ Agree

☐ Undecided

☐ Disagree

☐ Strongly disagree

1.2 Please justify your answer.

2. Circular economy and strong sustainability

2.1 Based on the respondents' answers to the previous survey, we have set a list of potential alignments between strong sustainability and circular economy. Please rank the following items in order of importance to you, first being the most important.

→ Attempt to stay within planetary boundaries
→ Degrowth
→ Focus on reduced consumption of virgin feedstock by keeping resources in closed loops
→ Job creation and social sustainability
→ Positive environmental value through strengthening ecological regeneration
→ Preserving the value od products, materials and resources as long as possible
→ Resource efficiency
→ Shift to renewable energy
→ Shift to renewable materials
→ Sustaining capital value over time

2.1.1 Do you have any further comments?

2.2 Based on the respondents' answers to the previous survey, we have set a list of potential conflicts or misalignments between strong sustainability and circular economy. Please rank the following items in order of importance to you, first being the most important.

→ Circular economy does not imply acting in nested circles: business (and economic activity) fully within social, then all within environmental limits; whereas this is required in strong sustainability.
→ Circular economy does not necessarily include the social sustainability dimension
→ Circular economy is not addressing a radical change in consumption patterns, required in strong sustainability
→ Circular economy is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model
→ Circular economy still promotes GDP growth
→ Circularity might entail keeping toxic substances in the loop
→ Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals
→ The circular economy features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to substitution of capitals
→ The energy needed for the closing loops is not always included in circular economy approaches
→ With a higher resource efficiency resulting from circular economy, rebound effects can occur, that will lead to an even higher resource use

2.2.1 Do you have any further comments?

3. Missing elements of the model

Based on the respondents' answers to the previous survey, we have set a list of potential elements that were missing and should be included in a model of design for a circular economy in a strong sustainability paradigm. Please rate their importance.

3.1 Understanding how the products, product-service systems and business models of the organization interact with the wider socio-ecological system they are part of.

☐ Very important

☐ Important

☐ Moderately important

☐ Slightly important

☐ Unimportant

3.2 Translating the higher-level goals and principles of CE in a strong sustainability paradigm into design criteria.

☐ Very important

☐ Important

☐ Moderately important

☐ Slightly important

☐ Unimportant

3.3 Establishing partnerships with stakeholders to jointly develop products, product-service systems, and business models aligned with CE and strong sustainability principles.

☐ Very important

☐ Important

☐ Moderately important

☐ Slightly important

☐ Unimportant

3.4 Inclusion of user and consumption perspectives into design processes to integrate them into circular and sustainable solutions principles.

☐ Very important

☐ Important

☐ Moderately important

☐ Slightly important

☐ Unimportant

3.5 Development and adoption of an integral measurement system to measure the progress and link the approach with the results.

☐ Very important

☐ Important

☐ Moderately important

☐ Slightly important

☐ Unimportant

3.6 Articulation between different individual projects (products, product-service systems, business models) and assessment of how they are interconnected at the company level.

☐ Very important

- ☐ Important
- ☐ Moderately important
- ☐ Slightly important
- ☐ Unimportant

The questionnaire ends here. Thank you very much!

F

ANNEX A

Examples of products and product-service systems illustrating the strategies of design for circular economy presented in chapter 4.

REVICOMFORT, by Revigrés

Description	REVICOMFORT is a porcelain stoneware flooring for interior areas, public or residential, removable and reusable, quick and easy to apply. It does not require adhesives, cement or specialized manpower and can be used immediately after application. It is a versatile, innovative solution in the ceramic world, which revolutionizes the concept of fixed flooring. REVICOMFORT brings together, in a single product, the technical characteristics of porcelain stoneware, the economic advantages of a simplified placement, the profitability of time in its placement, ease of mobility, ease of use and easy maintenance.
Organization and country	REVIGRÉS, Portugal
Sources	Company website: www.revigres.pt
Image	
Image source	http://revigres.pt/wp-content/uploads/2018/02/CAT_REVIGRES_PRO_2018.pdf
Sector	Construction
Circularity approaches	Slowing loops Narrowing loops
Design strategies	Design of long-life products Design for product-life extension Design for materials sustainability

ClickBrick, by Daas Baksteen

Description

The Clickbrick system is designed for reusability and a long life without maintenance. The bricks are dry stacked, assembled with steel clips, without using mortar. This results in fewer materials being used with an inherent ventilation system avoiding moisture. Whereas traditional bricks are usually at best downcycled at their end of life, the Click-Bricks can be disassembled and reused for the same purpose.

Organization and country

Daas Basksteen, The Netherlands

daas baksteen

Sources

Company Website: http://www.daasbaksteen.com/en/Facade-systems/Click-Brick/page.aspx/67

Image

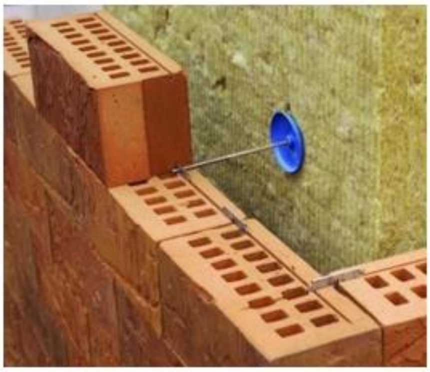


Image source

http://wiki.bk.tudelft.nl/mw_bk-wiki/images/thumb/2/22/Monsterk ast_168_1.jpg/400px-Monsterkast_168_1.jpg

http://www.c2c- centre.com/sites/default/files/styles/v2- single- page/public/click-brick.jpg?itok=rss7Dko

Sector

Construction

Circularity approaches

Slowing loops

Narrowing loops

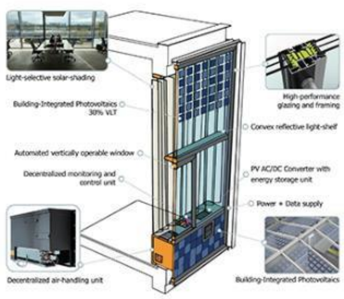
Design strategies

Design of long-life products

Design for product-life extension

Design for materials sustainability

Façade Leasing, by TUDelft

Description	An interdisciplinary research team within the Faculty of Architecture and the Built Environment developed a circular business model based on the use of multifunctional façades as performance-delivering tools. Under this scheme, the client is no longer the owner of the building envelope and its integrated building services, but instead leases them from a service provider through a long-term performance contract. Rather than purchase the façade panels as a product, the client hires the energy performance and user comfort services delivered to his building by this new façade system.
Organization and country	TU Delft, The Netherlands
Sources	https://www.tudelft.nl/en/architecture-and-the-built-environment/research/projects/green-building-innovation/facade-leasing/facade-leasing-pilot-project-at-tu-delft/
Images	 
Images source	https://d1rkab7tlqy5f1.cloudfr ont.net/BK/Onderzoek/Project en/RTEmagicC_Facade_Leasing_pilot_project_TUD_Panel2_Breakdown.png.pnghttps://d1rkab7tlqy5f1.cloudfront.net/_processe d_/8/9/csm_Leasing_facade_d6c5c7fb68.jpg
Sector	Construction
Circularity approaches	Slowing loops Narrowing loops
Design strategies	Design of long-life products Design for product-life extension Design of use- or result-oriented services Design for materials sustainability Design for energy sustainability

Treehouse Riga, by Jular

Description	Treehouse Riga is a modular home that can be easily adapted to the owner's needs. It is a prefab home, with less construction waste as compared to traditional construction methods, and expanding it to accommodate a growing family, for example, is a breeze. The basic version of Treehouse Riga measures 474 sq ft (44 sq m) and features two bed-rooms. It is made of just two modules. Each module measures 236 sq ft (22 sq m) and they are joined together in an offset way, which creates exterior spaces that slightly are different from each other. Presumably, more modules can simply be attached to the home, to create additional spaces such as extra rooms, a studio, a second bathroom and so on.
Organization and country	JULAR, Portugal
Sources	Company website: www.jular.pt ttps://www.treehouse.pt/construcao-modular/
Images	 
Images source	www.jular.pt
Sector	Construction
Circularity approaches	Narrowing loops
Design strat-egies	Design for materials sustainability Design for energy sustainability

Remade - G64-R office chair, by Orangebox

Description	Products that are reaching the end of their commercial life span are now being given a second chance, thanks to Orangebox Remade. The first product to be offered under this initiative is the G64, a very successful and durable office chair. 98% of the G64-R's parts are recyclable, with removed components either being kept for reuse or returned for material reprocessing. With a recycled content of around 80% (by weight), each remanufactured chair delivers a 60% reduction in CO_2 emissions and saves 75% of water consumption compared to new..
Organization and country	Orange, UK
Sources	Company website: www.orangebox.com https://www.orangebox.com/about/responsibility/remade
Image	
Image source	www.orangebox.com
Sector	Furniture
Circularity approaches	Closing loops Slowing loops Narrowing loops
Design strategies	Design of long-life products Design for recycling Design for remanufacturing Design for materials sustainability

Care Changing Table, by Stokke

Description	This design converts the changing table into a practical desk. It prolongs the use of the nursery products as the child grows, as it can be used as a place to play, draw or do the homework. Easy assembly.
Organization and country	STOKKE AS, Norway
Sources	Company website: www.stokke.com
Image	
Image source	https://www.stokke.com/en-za/164103.html
Sector	Furniture
Circularity approaches	Slowing loops Narrowing loops
Design strategies	Design of long-life products Design for product-life extension Design for materials sustainability

CIRCULAR DESIGN IN A STRONG SUSTAINABILITY PARADIGM

MARIA CRISTINA TOMÁS FERREIRA DE SOUSA ROCHA

2023