Perspectives on ecodesign implementation with quantitative analysis

Siru Sihvonen

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Abstract

Degradation and scarcity of natural resources at the planetary scale have triggered a context in which circular economy has emerged as a concept framing the discussion on these challenges. Companies are the critical stakeholders that should embrace circular economy thinking in order to take these discussions into practice. More specifically, such thinking should be explicated in product development where many of circular economy related aspirations are realized. This is examined in this dissertation from the perspective of the ecodesign domain. This dissertation consists of three published scientific articles, and a summary combining the results from these articles. This research provides new insights particularly from the soft-side of ecodesign which emphasizes the role of human factors influencing the uptake of environmental considerations in product development practices. It deepens the understanding of context for an enhanced ecodesign implementation by answering three research questions: Are there significant associations between ecodesign practices? To what extent circular economy considerations are associated with other ecodesign practices? And, how human factors, such as ecological concern, are related to ecodesign practices? Answers to these research questions are based on quantitative data using a descriptive research approach. The survey was conducted among people working with product development and representing various industries in Finland. The content analysis was based on data obtained from sustainability reports within one sector. Using content analysis allowed to extend understanding on the applicability of this research method within the ecodesign domain. These quantitative results contribute to the knowledge base by deepening the understanding of the current state of ecodesign practices. Results indicate that implementing ecodesign has progressed within proactive companies' product development. However, it is not yet a mainstream activity in the analyzed data. Established product development processes are associated with more formal management processes for environmental considerations within them. The results show the ways in which quantitative environmental targets for products are associated with circular economy related activities, and environmental performance within one sector. However, the awareness of circular economy is just emerging. These findings further indicate that the role of durability, and the way durability considerations enter the product development context should be further examined, as such considerations were not found to correlate with ecodesign practices apart from the earliest product development phase, nor with lifecycle thinking. Novel contributions were also achieved by using a scarcely applied unit of analysis within the field: the micro-level. This allowed a deepening in the understanding of human factors, such as ecological concern, and their associations with ecodesign practices. This dissertation provides new insights for companies struggling to implement ecodesign practices beyond their documentation.

Keywords circular economy, product development, ecodesign, ecological concern, ecological worldview

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Kiertotalous käsitteenä on noussut keinoksi keskustella maailmanlaajuisten luonnonvarojen heikentymisen ja ehtymisen haasteista. Yritysten tulisi vahvistaa kiertotalousajattelua omassa toiminnassaan, sillä yritykset ovat kriittinen sidosryhmä kiertotalouden implementoinnissa. Kiertotalouden implementointi voi lähteä usein liikkeelle yrityksen tuotekehityksessä, missä tällaista ajattelua tulisi lisätä. Tätä tutkitaan tässä väitöskirjassa ekodesignin näkökulmasta. Väitöskirja koostuu kolmesta tieteellisessä lehdessä julkaistusta artikkelista ja niiden yhteenvedosta. Väitöskirja nostaa esille uusia näkökulmia ekodesignin ns. pehmeältä puolelta, joka painottaa yksilötason tekijöiden merkitystä ympäristöasioiden huomioimisessa tuotekehityksessä. Väitöskirja syventää ymmärrystä tekijöistä, jotka vaikuttavat ekodesignin implementointiin yrityksissä, vastaamalla seuraaviin tutkimuskysymyksiin: Onko ekodesignikäytäntöjen välillä merkittäviä assosiaatioita? Missä määrin kiertotalouden huomioitiin linkittyä muihin ekodesignikäytäntöihin? Miten yksilöön liittyvät tekijät, kuten ekologinen ajattelu, linkittyvät ekodesignikäytäntöihin? Vastaukset näihin perustuvat kyselytutkimuksen ja sisältöanalyysin avulla kerättyyn aineistoon deskriptiivistä tutkimusotetta käyttäen. Kysely kohdennettiin tuotekehityksen parissa työskenteleviin ihmisiin Suomessa eri toimialoilta. Vastuullisuusraportit muodostivat sisältöanalyysin aineiston yhdeltä toimialalta kansainvälisesti.

Nämä kvantitatiiviset tulokset syventävät ymmärrystä ekodesignin implementoinnin nykytilasta. Tulosten mukaan ekodesignia toteutetaan proaktiivisten yritysten tuotekehityks konteksteissa. Se ei kuitenkaan ole vielä yleistä tutkitussa aineistossa. Käytössä olevat määrämuotoisemmat tuotekehityksen johtamisprosessit linkittyvät ympäristöasioiden määrämuotoisempaan huomiointiin. Tulokset osoittavat, miten yhdellä sektorilla tuotteiden kvantitatiiviset ympäristötavoitteet linkittyvät kiertotalouden käytäntöihin ja tarkasteltuun ympäristösuorituskykyyn. Tietoisuus kiertotaloudesta on tosin vielä vähäistä. Nämä tulokset saatiin sisältöanalyysin avulla samalla kun saatiin uutta tietoa tutkimusmenetelmän soveltuvuudesta ekodesignin tutkimiseen. Lisäksi tuotteiden kestävyttä tulisi tutkia tarkemmin tuotekehityksessä, sillä tässä aineistossa kestävyden huomiointi ei korreloinut elinkaariajattelun tai ekodesignikäytäntöjen kanssa lukuun ottamatta ympäristöasioiden huomiointia tuotekehitysprosessin alkuvaiheessa. Tämä mielenkiintoinen näkökulma laajentaa ymmärrystä ekodesignin toteuttamisen haasteista. Tutkimus tuo uutta tietoa keskusteluun käyttämällä tutkimusallalla harvemmin käytettyä mikrotason näkökulmaa. Sen avulla syvennettiin ymmärrystä myös siitä, miten ekodesignikäytännöt linkittyvät ekologisen ajattelun kanssa. Väitöskirja tuo uusia näkökulmia niille yrityksille, joilla on haasteita implementoida ympäristöasioiden huomiointia tuotekehityksessä.

Avainsanat kiertotalous, tuotekehitys, ekodesign, ekologinen suunnittelu, ekosuunnittelu, ekologinen ajattelu, ekologinen maailmankuva

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To Mamma and Pappa

Acknowledgments

If we think that life is a journey, then I would think that working on a dissertation is a voluntary part of that journey with an approximate beginning—and potentially an outcome in terms of a published dissertation. Little did I know at the outset what this path would entail in practice and, that today this outcome would feel as an intriguing invitation to new and renewed beginnings.

This research was carried out at Aalto University School of Engineering.

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Siru Sihvonen

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List of Abbreviations

CDP	Formerly known as Carbon Disclosure Project (CDP)
CE	Circular economy
EC	Environmental considerations
EoL	End-of-Life
EU	European Union
GRI	Global Reporting Initiative
ICT	Information and communication technology
NEP	New Ecological Paradigm
p-value	Probability value
ReX	Abbreviation for EoL strategies starting with prefix <i>Re-</i> ; such as Reduce, ReUSE (direct reuse, repair, re-purpose, refurbish, remanufacture, resynthesize), ReCYCLE, ReCOVER
SDGs	Sustainable Development Goals
U-test	Mann–Whitney Test
WEEE	Waste Electronic and Electrical Equipment

List of Publications

This dissertation consists of a summary and of the following publications which are referred to in the text by their numerals

1. Sihvonen, S., Partanen, J., 2016. Implementing environmental considerations within product development practices: a survey on employees' perspectives. *Journal of Cleaner Production*, 1 July 2016, volume 125, pages 189-203. DOI <http://dx.doi.org/10.1016/j.jclepro.2016.03.023>.

2. Sihvonen, S., Partanen, J., 2017. Eco-design practices with a focus on quantitative environmental targets: An exploratory content analysis within ICT sector. *Journal of Cleaner Production*, 1 February 2017, volume 143, pages 769-783. DOI <http://dx.doi.org/10.1016/j.jclepro.2016.12.047>.

3. Sihvonen, S., Partanen, J., 2018. A survey of perceived prevalence of selected environmental topics in product development, and their relationships with employee's ecological concern. *Journal of Cleaner Production*, 20 October 2018, volume 199, pages 1116-1129. DOI <https://doi.org/10.1016/j.jclepro.2018.07.092>

Author's Contribution

Publication 1: Implementing environmental considerations within product development practices: a survey on employees' perspectives.

The idea for this research originates with the first author, Siru Sihvonen. She has formulated the research objectives, decided on the research design, and conducted the survey. After receiving the results from the respondents, the first author has analyzed the data and prepared first versions of the paper including the literature review. The second author, Professor Jouni Partanen at Aalto University School of Engineering, has commented on draft versions of this article, which the first author has further edited for a submitted version. The first author of this article has developed it into a final version based on comments from five reviewers, and discussions with the second author.

Publication 2: Eco-design practices with a focus on quantitative environmental targets: An exploratory content analysis within ICT sector.

The first author, Siru Sihvonen, has proposed the idea for this journal article including the research questions. After a discussion with the second author, the first author has designed the approach to paper, chosen the research method, and conducted the analysis. Then, the first author has prepared first versions of the article including the theoretical background. As the second author, Professor Jouni Partanen at Aalto University School of Engineering has provided comments on draft versions of the article which have been edited by the first author for a submitted format. Six reviewers commented this article supporting the development of its final version by the first author.

Publication 3: A survey of perceived prevalence of selected environmental topics in product development, and their relationships with employee's ecological concern.

In this paper, the first author, Siru Sihvonen, has generated the idea of the research based on a discussion with the second author, Professor Jouni Partanen at Aalto University School of Engineering. The first author has formulated the research objectives; research design; re-analyzed further the survey data which is the same as in Publication 1; and prepared the early versions of the paper including the literature review. The second author has commented on draft versions of this paper which the first author has further edited for a submitted version, which was reviewed by two reviewers supporting the development of its final version.

1. Introduction

“Everything is vague to a degree you do not realize until you have tried to make it precise.” - Bertrand Russell (cited in Reid and de Brentani 2004)

This chapter briefly describes motivational factors for the dissertation by discussing the topical background and research gaps identified. It then introduces the research questions investigated in this dissertation on ecodesign. The chapter concludes with overview of publications, and information on the dissertation structure.

1.1 Background and research gaps

The voracious use of natural resources to satisfy the appetite of our societies has begun to limit opportunities for both current and future generations (United Nations 2015; Brundtland 1987). Namely, the level of degradation of the natural environment has been increasingly acknowledged to be on a planetary scale, partly due to the unbalanced metabolism of socioeconomic systems worldwide (Haas et al. 2015; Steffen et al. 2015). To counter this, shared understanding is sought to provide guidance in more detail. Currently one of the most globally recognized frameworks is the 2030 Agenda with its 17 Sustainable Development Goals (SDGs). One goal in this framework is the Goal 12, which seeks to “ensure sustainable consumption and production patterns” (United Nations 2015, see 2.1). Within this goal, one target is to reduce the amount of various wastes generated (ibid.).

In recent years, also a concept termed *circular economy* (CE) has been embraced to frame political discussion both on the scarcity of natural resources and their degradation in conjunction with economic growth, in addition to the pronounced adverse impacts of climate change. These two issues –resource degradation and climate change- are closely intertwined (Haas et al. 2015); however, addressing their impacts also demands different measures at various levels of societies including that of companies.

In the case of a circular economy, the principal idea is to keep materials and products introduced into a system to preserve their added value. This aims to restore a more balanced relationship between the needs of societies and the natural environment. Also, economic growth is sought to be decoupled from its adverse impacts to natural environment. One critical aspect in the circular economy thinking is the fundamental aim to transform linear product lifecycles into

more cyclical ones (see 2.4). This demands various concerted efforts among others at policy, regulatory and research levels, for which, for instance, many such activities are on-going within the European Union (EU) (Tecchio et al. 2017; Bundgaard et al. 2017; Vanegas et al. 2018; European Commission 2016; European Commission 2017; European Commission 2018a; European Commission 2019). However, among the most crucial efforts would be those of companies who are vital stakeholders in implementing such aspirations in practice. This interlinkage from policy to implementation by companies is also more broadly acknowledged in the SDGs; the role of companies in achieving these goals is now much more pronounced than in its earlier version, Millennium Development Goals (United Nations 2015; United Nations 2014; Stier 2014).

However, while seeking to advance the concept of a circular economy, stakeholders at various levels should also acknowledge the challenges encountered. To start with, progress related to a circular economy is currently understood burdensome to monitor at national level (Haas et al. 2015; European Commission 2018c); and for instance, in the EU, monitoring seems to focus on material flows (Eurostat 2018). Then, if there are no targets, for example, for waste prevention or reuse, it might not be worthwhile for industry to actually commit to waste prevention or reuse activities (Hogg et al. 2013; Bundgaard et al. 2017). Furthermore, a fundamental change would be envisioned for companies' underlying business logics, if typical linear value chains were turned into more cyclical ones (Stahel 2016; European Environment Agency 2017). In addition, it is also pointed out that pursuit of circular economy may fuel a search for unlimited growth which is understood impossible considering, for instance, planetary boundaries (Hauschild 2015; Bjørn & Hauschild 2013; Stevels 2016, p.70).

While these aforementioned issues touch some of the core issues within circular economy aspirations beyond companies to the societal levels, they are also closely intertwined with companies' product development in which many needed solutions would be realized in practice. These aspirations are ever more seen to provide a broad direction toward the expected outcomes from embedding environmental considerations, now increasingly framed as circular economy related ones (Bocken et al. 2017), into product development. Including environmental considerations into product development purposefully are understood as ecodesign (Please, see more definitions in 2.3), and its implementation issues are the overarching theme of this dissertation.

Namely, although ecodesign domain has witnessed plentiful, and solution-driven research (Boks & McAloone 2009; Li et al. 2015; Brones & Monteiro de Carvalho 2015), the adequacy of ecodesign implementation levels continue to be questioned based on empirical research (Bey et al. 2013; Short et al. 2012; Deutz et al. 2013; ADEME 2010). To counter this, since early 2000, a call for better integration of ecodesign into actual practices continues to be highlighted (Baumann et al. 2002; Brones et al. 2017; Boks & Stevels 2007; Hallstedt et al. 2010; Stevels 2009).

However, what is meant with implementation continue to be disputed as well as that of its targeted levels, although proposals exist (Pigosso et al. 2013; Boks & Stevels 2007; Hallstedt et al. 2010).

Baumann et al. (2002) suggest to addressing integration challenges by systematically studying the phenomenon from the perspectives of product development, company, between companies, and policy levels. Researchers point out the need for a more profound understanding of the multidisciplinary aspects of the phenomenon, and hence, researchers' review approaches issues from the viewpoints of management, engineering design, and policy literature. This coincides with the characteristics of product development being inherently a multidisciplinary activity: it combines various functions of any company wanting to have an idea transformed into a form ready for a sale, and beyond (Ulrich & Eppinger 2012; Krishnan & Ulrich 2001). Extending from this three levels approach, it is also important to understand better the internal and external value chain aspects when advancing environmental issues, and not focusing merely on activities for design teams (International Organization for Standardization 2011; Stevels 2009).

Furthermore, as also noted by Boks (2006), these levels by Baumann et al. (2002) ignore the potential influence of individuals on the behavior of system. This level of interest at the micro-level, which is a focus taken in this dissertation, continues to be less investigated in the empirical studies examining ecodesign (see Table 1 in Publication 1); although a need for such investigation is pronounced (Boks 2006; Handfield et al. 2001; Brones & Monteiro de Carvalho 2015; Dekoninck et al. 2016; Stevels 2016; Brones et al. 2017; Tingström 2007). Boks (2006) calls these micro-level issues as human factors that have mainly advanced along with research at a meso-level (Brones et al. 2017; Verhulst & Boks 2012). Notably, utilizing a micro-level analysis allows examination of attitudes and other motivational factors in more detail to determine in the ways they might be associated with ecodesign implementation issues. For instance, it allows the examination of the possible association of an individual's values toward the natural environment with implementing ecodesign practices. To date, it seems that this has not been studied earlier within a product development context, at least when measured with an ecological worldview coined by Dunlap et al. (2000; Hawcroft & Milfont 2010).

Boks and McAloone (2009) call for different approaches to advance the ecodesign knowledge. In this dissertation, the hurdles of implementing ecodesign are examined primarily from the perspective of an employee's interpretations of their product development project contexts. Then, this dissertation advances knowledge on ecodesign hurdles separately investigating product development phases (Boks 2006; Brones & Monteiro de Carvalho 2015), which further allows to the validation of results from Deutz et al. (2013).

Furthermore, another approach in this dissertation is to examine the extent of environmental quantitative targets as an indication of the capability to manage ecodesign (Krishnan & Ulrich 2001; Haapala, Karl et al. 2013; Sroufe et al. 2002). Although there exists conceptual discussion on target setting for ecodesign (e.g. Issa et al. 2015), it seems that less attention has been given to

the examination of the actual prevalence of quantitative environmental targets of products, aside from Bjørn et al. (2017) and Pascual, Stevels et al. (2003). Hence, this dissertation examines the challenges of implementing ecodesign within information communication and technology (ICT) sector by partly updating the study by Pascual, Stevels et al. (2003), in which companies' environmental management practices are categorized, including an evaluation of the level of quantitative environmental targets for products (KPMG 2015; Laurenti et al. 2015; Albino et al. 2009). This enables an exploration of the ways in which selected circular economy related activities may be associated with companies' ecodesign.

1.2 Research questions

This dissertation examines ecodesign implementation in product development. Ecodesign implementation consists of selected ecodesign practices. These ecodesign practices are investigated mainly related to product development process and individuals (O'Hare 2010). Examples of ecodesign practices include the ways in which ecodesign is managed within product development (Pigosso et al. 2013; see 2.3) or considerations for circular economy (The British Standards Institution 2017; see 2.4), such as considerations for durability (den Hollander et al. 2017), are taken into account.

This dissertation builds upon the knowledge accumulated through more than two decades of ecodesign research. Specifically, the perspectives in this dissertation seek to advance perspectives broadly posited within the applied ecodesign (Stevels 2016), and soft-side of ecodesign (Boks 2006; Boks & McAloone 2009). In essence, both these approaches call for research interlinking disciplines to better address the hurdles of ecodesign implementation, as well as to investigate issues from the level of individual at micro-level within the internal value chains. Among others, this latter perspective allows to examine the potential relationships between individual attitudes and ecodesign practices.

The research objective is to better understand the context for an enhanced ecodesign implementation within product development. To answer this, the following research questions are formulated from different perspectives:

- Research question 1 (RQ1): Are there significant associations between ecodesign practices?
- Research question 2 (RQ2): To what extent circular economy considerations are associated with other ecodesign practices?
- Research question 3 (RQ3): How human factors, such as ecological concern, are related to ecodesign practices?

For the research question one, mainly employees' perceptions are assessed to examine the extent of selected ecodesign practices, and the ways these practices might be associated with each other. In addition, the potential role of generic product development is specifically examined in fostering such practices. Fur-

thermore, an examination is carried out of the initially perceived role of environmental considerations in product development contexts, as well as the prevalence of quantitative environmental targets for products at the company level.

The research question two continues to examine the prevalence of selected circular economy considerations, building on topics deemed closely related to waste hierarchy. This research question examines the ways these may be associated with other ecodesign practices first assessed in answering the research question one. Additionally, it examines the extent of the awareness of selected circular economy related terms within reuse, and their relationships with the quantitative environmental targets for products, and the environmental performance. Both individual and company level of analysis is applied.

The third research question builds upon the previous ones. It assesses the extent of the ways that selected human factors, such as attitudinal and ecological concern, are potentially related with ecodesign practices including circular economy considerations. This examination is carried out at micro-level among the employees working with the product development. This provides one perspective to ecodesign implementation from those needed to effectuate them.

Figure 1. Focus areas for the publications.

Figure 1 above depicts the positions of the research questions and the three publications along two axes presenting potential dimensions to categorize this research on ecodesign. The vertical axis presents the unit of analysis applied in the research ranging from the perspectives of an individual at the micro-level to the company at the meso-level. Macro-level, denoting the level beyond the companies, is discussed in the introduction and theoretical chapters as well as touched upon in conclusions. The horizontal axis depicts the focus of the analysis ranging from specific tools or methods for products to the broader level processes within companies.

As the abundance of ecodesign tools and methods is pronounced in the literature (Baumann et al. 2002; Bovea & Pérez-Belis 2012; Lindahl & Ekermann 2013; Rousseaux et al. 2017), they are excluded from the scope of this dissertation. Furthermore, while circular economy concept can be approached from various perspectives, this research focuses on one of its core principles regarding waste hierarchy and systems approach (Kirchherr, Reike, et al. 2017). Hence, for instance, an empirical research related to business models in meso-level or policy implications at macro-level is beyond the scope, see e.g. Tecchio et al. (2017) or The British Standards Institution (2017).

1.3 Overview of publications

Table 1 below summarizes the publications appended to this dissertation.

Table 1. Overview of publications.

	Publication 1	Publication 2	Publication 3
Research objectives in the publication	"To assess current approaches for implementing environmental considerations into product development practices." "—to test these practices to identify associations between factors at micro-, meso-, and macro-levels."	"How mature and aware companies, within information communication technology (ICT) sector, are of selected terminology within circular economy sphere. —prevalence of quantitative environmental targets for products is examined. —relationships assessed with awareness—and environmental performance—."	"To deepen understanding around issues that might enhance product development practices toward extending products' lifespans."
Main domains	Ecodesign, product development, mental models, New Ecological Paradigm (NEP)	Ecodesign, environmental management, circular economy	Ecodesign, NEP, circular economy
Sample size, unit of analysis	n=51, individual	n=43, company	n=45, individual
Research method	Survey	Content analysis	Survey
Key findings	New insights on the perceived extent of ecodesign implementation.	New insights into the level of environmental quantitative targets for products within one sector, and the ways they are related to selected circular economy considerations. Assessment of the applicability of content analysis within the domain.	Insights on the perceived prevalence of selected circular economy considerations, and their relationship with ecodesign practices. New understanding of the role of ecological concern in enhancing ecodesign implementation.

These publications provide examples on the ways to determine the current extent of ecodesign implementation based on empirical research.

Table 2. Linking research questions and publications.

	Publication 1	Publication 2	Publication 3
RQ1: Are there significant associations between ecodesign practices?	X^a	x	x
RQ2: To what extent circular economy considerations are associated with other ecodesign practices?		X	X
RQ3: How human factors, such as ecological concern, are related to ecodesign practices?	X		X

(^a "X" in bold refers to publication as the main source for the research question)

Table 2 in the previous page provides an overview of the way each publication answers the research questions posed. It shows that for the RQ1 all publications provide part of the answer, although the Publication 1 is the primary source. Whereas for the RQ2 both Publication 2 and 3 provide answers equally; answers for RQ3 are obtained primarily from the Publication 3.

1.4 Dissertation structure

This dissertation consists of this summary as well as the original publications at the end. This summary contains six chapters.

The purpose of this introductory chapter was to guide reader into the topic starting with the background fueling the motivations for the research, narrowing down to describing the research gaps, research objective and related research questions, and the way different publications provided support in answering the research questions (Table 2). It also provides the overview of publications.

Chapter two introduces the theoretical perspectives that have guided the research approach applied. It starts with macro-level discussing the SDGs and circular economy. Chapter then continues describing generic product development perspectives in order to highlight the reasons the focus areas of this research are specifically in the early product development phases. It then continues to discuss the role of ecodesign in advancing the debate on implementing environmental considerations into company practices, and the ways selected circular economy aspects are seen as interlinked topics. This chapter then proceeds to introduce selected human factors.

Chapter three describes research methods and data used in this dissertation.

Chapter four is structured in such a way that it enables the locating of results labeled as a combination of theoretical foundations and research questions.

Chapter five discusses research results based on the research questions posed. This chapter also reflects these findings with literature and ends by discussing the limitations of the research.

Chapter six concludes the research conducted for the dissertation by discussing its contributions to the base of knowledge, and by suggesting ideas for future research.

2. Theoretical foundations

This chapter discusses theoretical perspectives with a cascading order starting from macro-level continuing with meso-level, and ending the chapter with discussion on individuals at the micro-level.

2.1 Theoretical perspectives on linking SDGs and circular economy at macro-level

This section briefly describes two recent developments in which the role of companies is explicitly articulated at macro-level: One is the endorsement of the SDGs and the other is the recently accelerated discussion on circular economy.

First, the emerging concept of circular economy is understood as an umbrella thinking that seeks to integrate different schools of thought (Blomsma & Brennan 2017; The British Standards Institution 2017). Recent research (e.g. Bocken et al. 2016; Ghisellini et al. 2016; Blomsma & Brennan 2017; Reike et al. 2018), traces concept of circular economy, among others, back to Boulding (1966) who described planetary boundaries using term *Spaceship Earth*, and the early understanding of systems thinking (Senge et al. 2008, p.179, 186). Due to circular economy's potentiality to offer a paradigm shift in thinking, its definitions continue to have various interpretations (The British Standards Institution 2017; Kirchherr, Hekkert, et al. 2017; Blomsma & Brennan 2017). In the context of this research, a circular economy is defined as a system that is by intention restorative for the technical cycles or regenerative for biological cycles (Ellen MacArthur Foundation 2013; The British Standards Institution 2017).

Then, the 2030 Agenda is one of the major globally agreed frameworks to address challenges for sustainable development at a planetary scale. The 2030 Agenda titled "Transforming our world: the 2030 Agenda for sustainable development" was adopted as a declaration by 193 nations in United Nations General Assembly in September 2015. It contains 17 SDGs with 169 targets and 232 unique indicators, which are universal and applicable to all countries (Appendix 1). Despite the large amount of measures, they are interlinked with each other also through five themes: people, prosperity, planet, peace, and partnerships. (United Nations 2015; UNSTAT 2018b)

The role of companies' in achieving the SDGs is critical together with other stakeholders, such as governments, civil society organization, and citizens. For

instance, the Goal 17 looks at ways to enhance partnerships to tackle these interlinked challenges together. In overall, the role of business can be interpreted as twofold: to act responsibly and to innovate solutions to address global challenges (Global Reporting Initiative & United Nations Global Compact 2018).

However, achieving the SDGs necessitate a transformational change worldwide among others in the ways products and services are produced and consumed. Similarly, circular economy is seen as one such solution; yet the concept as such was not mentioned in the 2030 Agenda. Instead, the concept was indirectly touched upon in the Goal 12, containing 11 targets, in ensuring sustainable consumption and production. For example, target 12.5 states that “By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse” (UNSTAT 2018a); yet, the indicator for this target does not contain prevention measures.

Few researchers have already found interlinkages with the SDGs, and the aspirations of circular economy. Schroeder et al. (2018) find that circular economy and SDGs are directly linked with 21 targets out of 169 targets in total, while indirect associations are claimed for an additional 28 targets (Figure 2). Moreover, researchers (ibid.) argue that several more SDGs would benefit from enhanced circular economy practices, such as those existing under the Goal 1 regarding eradicating poverty. However, it is also argued that circular economy concept does not yet contain broader aspects of sustainable development (Kirchherr, Reike, et al. 2017).

Figure 2. Potential interlinkages between CE and SDGs in emerging economies (adapted from Schroeder et al. 2018).

The ways in which companies manage their products and services have implications to a wider society – both positive and negative. Therefore, it is intriguing to explore ways, in which these implications could be sustainable on a longer term. And, one appropriate place to start might be where these products and services are often initiated: the product development.

2.2 Theoretical perspectives on product development at meso level

What is a definition for a process within a company that brings a new idea to a market ready for sale? Probably depending on whom this question is asked from, different answers would emerge. Someone from the marketing might define that as new product development without necessary detailing it, a person from management might call it an innovation process, a person from supply chain background might start mapping it within the supply chain management frameworks, and a person with a background from engineering design might see it as product development including an iterative process with several pre-defined steps. Nevertheless, many of these alternatives would likely have some kind of a stage-gate process included (Cooper & Edgett 2012, see also Figure 3). These potential perspectives add necessary dimensions to address anything from idea generation to the ways a product or service actually could be sold in the market place, and beyond. They are valuable approaches in increasing the understanding of various inputs and outcomes that are needed to effectuate such an activity within a company.

The approach taken in this dissertation is to understand the process as a product development process that would include a set of supportive, both managerial and operational, structures and processes which are actually practiced beyond their documentation (Cooper & Edgett 2012; Ulrich & Eppinger 2012). What these structures and processes actually contain, and the ways they are managed depends among others on the speed of industry that a company operate in (Ulrich & Eppinger 2012). Processes are understood as customized routines to communicate, coordinate, and integrate the product development activities (Teece et al. 1997). Competences to manage these processes may eventually mature into dynamic capabilities following a pattern of path-dependence in which learning through choices made is assumed to accumulate with time (ibid.).

Furthermore, employees may perceive the extent of these formal management processes differently. For instance, findings from a study among new product developers in the United States indicate that 69 percent of respondents consider their employers' new product development processes being formally managed (Barczak et al. 2009). However, the percentage drops down to 55 percent, when they were asked about the extent of formal processes for a portfolio management. Nonetheless, the study does observe a trend toward more structured product development processes in general. (Ibid..)

Product development processes are typically customized to fit an organizational context, and perhaps there is no 'one solution fits all' for its successful format (ibid.). In addition, several models exist to describe these processes (Gero & Kannengiesser 2004; Ulrich & Eppinger 2012; Pahl et al. 2007; Howard et al. 2008). Yet, many of these models have one common denominator in addition to some type of a stage-gate activities. Namely, design activities are likely purposefully performed within these proposed models to decide through exploration and learning how to bring about an idea into a form ready for the markets in a constrained world (Gero & Kannengiesser 2004; Ulrich & Eppinger 2012). One model to describe this design activity is a function-behavior-structure

(FBS) model which seeks to establish relationships between these three elements (Gero & Kannengiesser 2004). Noteworthy in this model is that relationship is not direct between function and structure; instead actual behavior is assumed to guide the structure, and not the expected behavior, as the latter might differ from the actual one.

The function in FBS model is seen as a reason for a given object to exist, while the behavior is about what the object is performing, and a structure refers to what the object is in terms of linked components (Gero & Kannengiesser 2004). On the other hand, Andreasen (2011), suggests understanding a function as what the product can do, and what we can do with the product. Meanwhile, when discussing the meaning of specifications, Ulrich and Eppinger (2012, p.92) refer to what the product has to do.

One model to describe product development process is depicted in the Figure 3 below. This figure visualizes how iterative thinking allows to proceed toward a final solution through both divergent and convergent stages. What is interesting in this overall model is the lack of explicit considerations of the phases after the solution is in use. This is aligned with findings by Howard et al. (2008): approximately half the engineering design models that these researchers reviewed did not contain implementation as a step within engineering design process either, while the rest of those reviewed models did contain it in a form or another.

Figure 3. An example of product development process (Ulrich & Eppinger 2012, p.14).

Product development largely determines the product characteristics throughout the life-cycle, including among others forthcoming product's functionalities, quality, and costs. As an example, in one case study it was examined how much design efforts would influence manufacturing costs for coffee kettles (Ulrich & Pearson 1998). Researchers estimate that to be around 50 percent when other variables were kept the same. Yet, many decisions at early product development

are shadowed by uncertainty according to designer's paradox (Lindahl 2005, p.13): once more is known at later phases, less space remains left to maneuver.

Typical objectives set for product development process include product cost, performance, development program expense, and most notably the speed of development (Thomke & Reinertsen 1998). Table 3 below depicts examples of potential targets for product development highlighting the various perspectives on the ways that targets might be addressed within companies. Barzack et al. (2009) report that around two thirds of the new product development teams have specified goals and objectives for their projects, and increasingly so in organizations that successfully introduce new products to markets. More successful companies would also embrace measures to support cross-functional communication: in these companies, progress is also evaluated with more formalized idea generations processes (ibid.).

Table 3. Examples of targets for the product development projects (adapted from Krishnan and Ulrich 2001).

Marketing	Organizational	Engineering design	Operations management
Market share	Project success in terms of time or budget	Form, function, cost	Efficiency, total cost, time

In practical sense, one critical document in product development is the document in which the forthcoming product's requirements, or target specifications, are agreed in solution-neutral format (Pahl et al. 2007). This document is usually regarded as a normative document guiding the next phases of product development process being itself an outcome of task clarification and the planning phase (ibid.). As visualized in Figure 3 in the previous page, all the early discussion at planning phase are combined into this one document setting the ambitions, or target characteristics, for the forthcoming product so that process may then continue iterating again between divergent and convergent stages until final solution is ready for sale. Document's contents are iteratively updated up till conceptual stage in which the final product specifications are set including both metrics and values attached to them (Ulrich & Eppinger 2012, p.93). For instance, Pahl et al. (2007) provides a list of topical areas to consider within the requirements including aspects, such as geometries, materials, quality, and how product should be produced, transported, maintained, and how much all this may cost. Ulrich and Eppinger (2012) prompt that these should be translated into technical specifications based on customer needs. These examples demonstrate the nature of requirements necessitating cooperation with multiple functions in companies.

2.3 Theoretical perspectives on ecodesign

Linking environmental considerations within existing product development processes and practices discussed in the previous section are assumed to enhance the leverage for their actual implementation (Stevens 2009; Stevens 2016; Deutz et al. 2013; Johansson 2002; International Organization for

Standardization 2011). This section discusses what is understood by such environmentally benign processes and practices called ecodesign.

One central idea in ecodesign (Table 4), and in life-cycle engineering, is to consider the whole lifecycle of a forthcoming product from raw material extraction to final disposal (International Organization for Standardization 2011; Hauschild et al. 2005; Stevels 2016). At large, applying such lifecycle thinking in practice would stress a need to consider how to address potential environmental impacts both down- and upstream beyond companies' direct boundaries (Hauschild et al. 2005). However, priority areas differ considerably on what these lifecycles would entail in more details (see one example in Figure 4), what should be the most prioritized issues in the first place, and how ecodesign should be implemented within companies' product development.

Table 4. Selected definitions on ecodesign.

Term	Definition	Source
Lifecycle engineering	"Life cycle engineering is the art of designing the product life cycle through choices about product concept, structure, materials and processes, and life cycle assessment (LCA) is the tool that visualizes the environmental and resource consequences of these choices."	(Alting & Legarth 1995)
EcoDesign	"--- an activity aimed at lowering the environmental load of products/functionalities over their life cycle."	(Stevels 2009 p.23)
Ecodesign	"--- integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle."	(European Union 2009)
Ecodesign	"--- integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle."	(International Organization for Standardization 2011)
Ecodesign	"--- a proactive environmental management approach that integrates environmental issues into the product development and related processes."	(Pigosso et al. 2013)
Ecodesign	"Incorporating environmental aspects into projects and product development process of business with a life cycle perspective."	(Brones & Monteiro de Carvalho 2015)
Ecodesign	"--- is a proactive environmental management and improvement approach employed in the product development process, which aims to minimize the environmental impacts caused during a product's life cycle and thus improve its environmental performance."	(Issa et al. 2015)

In this dissertation, ecodesign definition incorporates the understanding of term as an environmentally benign management approach in product development, and related functions such as sourcing, with a purpose to embed environmental considerations into companies' generic product development processes considering the lifecycles of products (Pigosso et al. 2013; Lenox & Ehrenfeld 1997). Put it differently, this applied definition entails both the application of environmental considerations within product development and related functions as a practice, and the management of such practices (International Organization for Standardization 2011; Pigosso et al. 2013). Hence, it extends among others the definition from the EU directive shown in the above Table 4.

Emerging from the early 1990's into a broader scale within academia, ecodesign matured into an established research domain by the late 1990's (Hauschild et al. 2005; Boks & McAloone 2009; Li et al. 2015). According to Boks and McAloone (2009), research has been going through several transitions from early attempts that concentrated on the disassembly techniques, to aspects including the user-centric design, and product portfolio in recent years.

Figure 4. Potential ReX strategies along a potential lifecycle (adapted from Sihvonen and Ritola 2015).

Researchers (*ibid.*) conclude by suggesting more detailed research on human factors, metrics, and customization to advance the discipline. On the other hand, Stevels (2009) compares longitudinal progress between topical issues within academia versus practice related to ecodesign. Researcher argues, for instance, that while academia pursued the integration of lifecycle thinking, industry was seeking ways to integrate environmental considerations into their business in order to meet regulatory demands and to create value (Stevels 2009, p. 9). Perhaps surprisingly, opinions seem to continue differing in whether cross-disciplinary discussion should be entailed, or not (Krishnaswamy & Chandran 2017). If the interest is on implementing environmental considerations within product development processes in practice, multi-disciplinary approaches seem necessary (Baumann et al. 2002; Pascual, Boks, et al. 2003; Brones & Monteiro de Carvalho 2015).

Lenox and Ehrenfeld (1997) postulates that environmental design capabilities (called ecodesign capabilities thereafter) consist of three dimensions at the meso-level. These capabilities reside in companies' processes

- to create knowledge structures in expertise for environmental considerations,
- to interpret these environmental considerations as so valued elements that they would be incorporated into the product development processes, and
- to communicate what is expected regarding environmental considerations.

These three ecodesign capabilities are assumed to take time to mature similarly to generic product development capabilities (Teece et al. 1997). As an example, the way path-dependence has accumulated into dynamic capabilities for ecodesign is documented in one company providing energy-using products (Stevels 2009; Stevels 2016), similarly to another research (O'Hare 2010).

Table 5. Selected examples on the levels of ecodesign implementation based on empirical research.

Authors	Definition of implementation/practice	Examples of findings (Type of research)
Lenox et al. (1996)	Formal process means combining procedures, practices, and methods that foster design with environmental consciousness.	Formal processes exist in 20% of organizations (Quantitative, n=81)
Handfield et al. (2001)	Ideal integration if 1) both corporate and PD have objectives for environment; 2) PD process has environmental in all main checkpoints, and environment has same weight than other design goals, and 3) environmental outcome is measured as part of product launch.	1) No formal processes for environmental goals, not part of design goals, mainly part of exit/checklists; 2) Mainly material related, not having same weight than other criteria, trade-off 3) If measured, least important. (Qualitative, n=10)
Lindahl (2006)	Method as facilitating in finding a goal or answer in a systematic and predefined way and tools as physical means assisting this activity	None of respondents mentioned use of Design for Environment tools, while almost all mentioned generic product development methods/tools. (Qualitative, n=12 in one company)
Petala et al. (2010)	Amount of design briefs containing information on environment or sustainability at Unilever's Dressing (D) and Savory (S) divisions	Little explicitly used in the studied design briefs: in D-division 16 out of 117, and in S-division 14 out of 20. (Quantitative, n=202 briefs)
ADEME (2010)	(Author's translation from French): Systematic ecodesign for all companies' products; for one or more products; interested but not yet started with; not interested; and not applicable	20% systematic approach for all products; 13% for one or more products; 29% interested not started; 22% not interested; 16% not applicable (Quantitative, n=373 in France)
Short et al. (2012)	Practice of design for sustainability and ecodesign (yes/no). "Design for Sustainability is the practice of understanding the customer and economic requirements for a product, along with the need to improve both its environmental and social impact, and then considering and balancing all these factors during its development." "Is Design for sustainability practiced in your company? Yes/no" "Is ecodesign practiced in your company?" Yes/no!	Design for Sustainability: Yes by 58% of large companies in United Kingdom (UK), and 79% in Sweden; Ecodesign: Yes by 42% of large companies in United Kingdom, and 45% in Sweden; 35% by small companies in UK, and 12% in Sweden (Quantitative, n=54 in UK and n=72 in Sweden)
Deutz et al. (2013)	Frequency to apply (often/very often) environmental issues within separate product development phases: design briefs, functional requirements, conceptual design, detailed design	Ranging from 43% to 52% depending on the product development phase, for instance 45% for functional requirements. (Quantitative, n=93)
Poulidikou et al. (2014)	Design for Environment approach implementation represented through work procedures, people, Design for Environment tools and requirements	Different approaches: 3 out of 4 companies had structured Design for Environment process, in-house environmental expertise; 2/4 had tool expertise. (Qualitative, n=18 in four companies)
TNS political & social (2018)	"What actions is your company undertaking to be more resource efficient?"; 1) "Designing products that are easy to maintain, repair, and reuse"; 2) "Does your company offer green products or services?" 4 alternatives: "Yes/no but planning in next two years/no and not planning/don't know-not answered"	1) 25% for average in 28 European countries, 33% for France and 23% for Finland 2) 24% yes, 9% no but plans to, 63% not planning to offer (Quantitative, n=12 907 SME companies in EU28)
United Nations Global Compact (2018)	"What actions does your company take to implement the environmental principles?" "Eco-design"	28.7% Eco-design (Quantitative, n=1140, member-companies)

Brones and Monteiro de Carvalho (2015) suggest that environmental considerations should be integrated into three levels within product development including tactical, process, and strategic levels. For example, findings by Deutz et al. (2013) show that it may be infrequent to include environmental issues in the functional requirements, and in the design process in overall. To assess the extent of formal implementation, it might be insightful to also understand what

type of role is given to environmental considerations, and what types of communication networks and knowledge structures are established to support their implementation (Johansson & Magnusson 2006; Lenox & Ehrenfeld 1997).

Implementing ecodesign is not without its challenges (Dekoninck et al. 2016; Handfield et al. 2001; Boks 2006; Short et al. 2012). Stevels (2016) postulates that internal and external value chain issues related to flow of information, material, and money may be equally important – if not more important in determining the way the product characteristics may end up being. And specially so if emotionally laden-topics, such as environmental topics, are to be considered within these value chains.

One way to approach implementation issues is to examine the ways environmental considerations are operationalized formally in the product development processes. Table 5 in the previous page provides examples of the extent of ecodesign implementation based on selected empirical research. As can be seen from the table, different ways to define this is applied in empirical research.

For instance, one French study finds that one in five companies had operationalized environmental considerations in all their products, whereas 13 percent of respondents reports doing so in one or more products (ADEME 2010). In another study, it is shown that 25 percent of small and medium-sized companies in 28 European countries “design products that are easier to maintain, repair or reuse” (TNS political & social 2018). Such internal activities might be communicated for example so that company offers green products or services: In this European-wide study, 24 percent of the SMEs reports doing so compared to 49 percent of larger companies (ibid.).

To start with assessing the extent of current ecodesign practices, quantitative measurable environmental performance metrics, as a proxy for knowledge and communication within the ecodesign capabilities, could demonstrate the current maturity level of such practices (Haapala, Karl et al. 2013; Krishnan & Ulrich 2001; Sroufe et al. 2002). To emphasize the relevance of this, Donnelly et al. (2006) demonstrate how environmental objectives and targets glue the company’s environmental product management, and product development processes together. Linking the discussion from the section 2.2, Table 6 below provides examples of potential targets that could be chosen to address environmental aspects related to product development. These examples exhibit the ways that the focus of targets may shift depending on the outcome perspectives, and the maturity level of ecodesign practices (Pigosso et al. 2013). The type of metrics could also be categorized into two: those related to products –specific or generic concerning the whole product portfolio-, or to the ecodesign process (International Organization for Standardization 2011).

Table 6. Examples of potential environmental topics as targets (adapted from Publication 2).

Marketing	Organizational	Engineering design	Operations management
The percentage of ecodesigned products in product portfolio	Integration of ecodesign into processes, e.g. in project gates, and functional requirements	Reduce potential toxicity, less materials, and energy consumption	Reverse logistics e.g. re-claimed volumes

As previously mentioned, early phases of product development are assumed to largely determine the intended product functionalities. It is similarly assumed that the forthcoming environmental fate for these product characteristics become largely locked-in during these early phases where trade-offs need to be tackled with (McAloone et al. 1998; Luttrupp & Lagerstedt 2006; International Organization for Standardization 2011). In a recent article, Deutz et al. (2013) posit that environmental considerations should be included within functional requirements with an idea that considerations for what a given product should accomplish in this regard, should expand beyond the use phase to also include other lifecycle phases. Although this suggestion may first sound compelling to the proponents of ecodesign, however, functionality should carefully be defined as it may have more meanings than a behavior, as discussed in the previous section. Furthermore, findings by Petala et al. (2010) show that merely including sustainability topics within design briefs without a proper consideration, or actionable elements, may not bring about the desired outcomes. So, in addition to the physical functionality as to the ways the forthcoming product behaves, care should be taken to determine the amount of such functionalities to be included (Stevens 2016, p.46). Stevens (ibid.) categorizes functionality thinking into four dimensions in which environmental issues could be considered among other aspects. These dimensions include the aforementioned physical functionality, and the aspects of economical, emotional, and intangible functionalities. The question is how to determine these along several lifecycle stages of a forthcoming product.

Handfield et al. (2001) and McAloone et al. (1998) suggest to address responses to potentially adverse environmental impacts early in the product development, and to consider them on a par with other criteria before the requirements are settled on. It is assumed that if environmental considerations are excluded from these early phases in the first place, likelihood will increase for their absence in the product development process later on. To enhance this early inclusion, Dewulf (2013) argues that more research is needed to better understand how to integrate sustainable design into this front end of the design. For instance, prioritization of related potential targets should occur at some point in these early stages; Then, they may be better refined into the actual product specifications in the process later (International Organization for Standardization 2011; Issa et al. 2015).

It is important to acknowledge that environmental topics are but one set of trade-offs that needs to be tackled in the product development (Luttrupp & Lagerstedt 2006; International Organization for Standardization 2011). In addition, each set of a new topics will add complexity to the decision-making situations. In order to broadly clarify these complexities, Prendeville et al. (2017) propose to categorize trade-offs into four dilemma dimensions that constraint the product development decisions. These four dilemma dimensions include characterizations of dilemmas into opposite directions, hierarchical directions, contradictions, or that issues to be considered might be simply overlapping with

each other. All these potential dimensions would create tensions in the decision-making situations.

This section has discussed on the how aspects of the ecodesign implementation without detailing environmental aspects. Three environmental aspects - emissions, potential toxicity, and resources- are assumed to cover the overarching understanding of the environmental issues (Boks & Stevels 2007; Stevels 2015, p.16). In the next section, circular economy lens is used to discuss selected issues concerning the aspect of resources.

2.4 Theoretical perspectives on linking ecodesign with circular economy

One starting point for any of the potential circular economy strategies that a company may opt-in, is the issue on how to make its value chains more circular in a world of complex products, globalized networks, and markets. Two potential range of circularities are assumed possible: products or materials, or something in between them depending on, among others, on their inherent complexities. More importantly, choices made within this continuum, as visualized in Figure 5 below, will have an impact on suitable business models that would likely differ from each other toward either slowing or closing the loops (Stahel 2016; Bocken et al. 2016). For the product development, these choices would provide different impetus in practice if circularity were targeted rather through products than materials, or vice versa. In addition, the system in which these products would be introduced, will also have an impact to the potentiality of the circularity on chosen dimensions to actually occur. (European Environment Agency 2017; The British Standards Institution 2017).

Figure 5. A simplified value continuum of two circularity aspects (Publication 3).

Before such choices toward circularity could be pursued more effectively in the product development, it is argued that internal stakeholders from various backgrounds should share the understanding what is meant with these potential choices more unambiguously. According to The British Standards Institution (2017), such discussions are pivotal in order to frame and scope the intended circular economy strategies. For instance, one friction may arise in the micro-level if some individuals perceive these choices as opportunities while others might view them as a challenge instead (Sharma 2000). Before making a choice, a proper discussion for shared definition of potential options is expected to support alignment of the forthcoming priorities for instance, within product development phases. When such discussions are delayed to later stages of product development, they may lead to sub-optimal outcomes due to less design space

available to influence product characteristics (McAloone et al. 1998; Tanskanen & Takala 2003).

One way to increase such shared understanding is to properly discuss the definitions for end-of-life (EoL), although within the recent circular economy aspirations there seem even ambitions to replace the need for the EoL altogether (den Hollander et al. 2017; Kirchherr, Reike, et al. 2017; Ellen MacArthur Foundation 2013). Nonetheless, extant research provides abundant definitions for end-of-life to choose from, it is not necessarily unambiguously defined in regulatory frameworks (Gharfalkar et al. 2016; Sihvonen & Ritola 2015). For those in product development that are not yet familiar with waste management issues, the term *end-of-life* might easily connote with understanding it literally. To counter this, some researchers tend to frame term more positively. For example, Ciceri et al. (2010) contextualize ending as part of the three group of lives: Beginning of life (BOL), Middle of Life (MOL), and then End-of-Life (EOL). Another proposal is to pronounce its outcome as a New Life (Peeters & Dewulf 2012). These researchers exclude incineration, illegal waste treatment, and landfill in their proposal (ibid.). Sometimes, term *retirement* is used to replace term EoL (Telenko et al. 2008). So, it is assumed that it may not always be clear what is actually ending; for example, whether it is the useful life in overall (Murakami et al. 2017) or the end of the first life (Allwood et al. 2011).

In this research, EoL strategies are envisioned as ReX strategies. ReX stands for *Re-* for a prefix meaning ‘afresh’, ‘new’, originating from Latin (‘back’ and ‘again’) (Oxford living Dictionaries 2017b). *X* is for various options to develop a forthcoming product considering its lifecycle from a perspective of one or several users: before it is in use (*Pre-use*), during use (*Use*), and after use (*Post-use*). Term *ReX* seeks to inspire individuals early in the product development by positively inducing increased shared understanding what could be targeted for.

Figure 6 in the next page provides an illustration the ways these alternatives could be positioned within different lifecycle phases highlighting the importance of each. This explicitly includes that of prevention possibilities during the Pre-use phase acknowledging their controversial role (Kirchherr, Hekkert, et al. 2017; Lansink 2014). In addition, Table 7 in page 30 provides their differentiating aspects in terms of quality, identity and level of disassembly. Sihvonen and Ritola (2015) have built this proposal on ReX strategies based on systematic literature review, EU’s waste hierarchy (European Union 2008), and an overall ecodesign framework guidelines by Luttrupp and Lagerstedt (2006). Similar to the study by Peeters and Dewulf (2012), landfill and incineration are explicitly excluded as no-ReX strategies. This type of thinking is similar to circular economy’s aspirational “design out waste” ideal, in which it is envisioned to replace waste with these types of strategies (Kirchherr, Reike, et al. 2017; den Hollander et al. 2017; Bakker et al. 2014; Ellen MacArthur Foundation 2013; The British Standards Institution 2017).

Two considerations are assumed to provide leverage for circularity of product flows: recognizing product’s adverse impact on natural environment from the

lifecycle perspective, and seeking to establish aspirations for extension of life-time in use (Ardente & Mathieux 2014; Dalhammar 2016; Bakker et al. 2014; den Hollander et al. 2017).

Figure 6. Potential ReX strategies with selected circular economy considerations (adapted from Sihvonen and Ritola 2015. This is licensed under the CC-BY-NC-ND 4.0 international licence permission from Elsevier B.V.).

To reiterate, one primary concern within circular economy perspective pertains on issues how to extend the use phase of products. Examples of such reuse alternatives may range from direct reuse to repair, refurbish to remanufacturing activities (Figure 6). Different meaning attached to these terms may create confusion what these different approaches signify in practice, and hence, hindering their advancement (Gharfalkar et al. 2016; Sihvonen & Ritola 2015; Hatcher et al. 2011). For instance, if remanufactured products are offered both with and without warranties, customers may not differentiate between products treated this way, and with simple repair or refurbished products (Gharfalkar et al. 2016; Tan et al. 2014). In addition, fundamental shifts in earning logic might be forthcoming if ReX strategy toward remanufacturing were pursued. Such a strategy would necessitate considerations of systems of products in addition to the system of single products (Manzini and Vezzoli cited in Ramani et al. 2010, The British Standards Institution 2017).

Post-use, as understood in this research, concerns various recycling processes ensuring collection and treatment of products, and recovery of hazardous or valuable materials from them (Ilgin & Gupta 2010). Such recovery activities would have outcomes categorized, according to European Commission (2018b), as “recovered materials” to denote articles, mixtures or substances identified as no longer waste, while “recycled materials” would then be understood as materials still potentially regarded as waste. And before this, companies should understand what are these volumes (see also Table 6). To increase this understanding, companies are encouraged to report volumes of their reclaimed products while disclosing their progress on SDGs, namely when reporting on the SDG12, SDG12.5 (Global Reporting Initiative & United Nations Global Compact 2017, p.142).

Table 7. Overview of ReX strategies (adapted from Sihvonen and Ritola 2015).

ReX strategy	Identity	Expected quality	Level of disassembly
Reduce	Original	New	None
• Refuse	None	None	None
Reuse			
• Repurpose	Original	'As-is'	None
• Direct reuse	Original	'As-is'	None
• Repair	Retain	Working order	Product/down to faulty part
• Refurbish	Retain	Specified level	Module
• Remanufacture	Retain	'Like-new'	Part
• Resynthesize	Lost	Low-high	As needed
Recycle	Lost	Low-high	Material
Recover	Lost	Low-high	Substance

The efficacy of these recovery processes may be enhanced with decisions made earlier in the product development. For example, identification of materials and choosing compatible material groupings would enhance their recovery activities (Issa et al. 2015; Khor & Udin 2013; Luttrupp & Lagerstedt 2006). To support this, Deutz et al. (2013) argue that functionality considerations should indeed entail more than just use phase in order to support, for instance, the recoverability of valuable or hazardous materials at post-use phase.

A practical start toward this direction might be committing to quantitative targets for reclaiming products through various types of take-back programs. This might further induce emergence of different types of external value chain partners in addition to upstream partners enhancing the compatible product properties for recovery (Stevens 2016; The British Standards Institution 2017).

This might necessitate among others a deeper understanding of the disassembly aspects together with downstream partners, such as recyclers. As an example, this cooperation with recyclers is encouraged among producers of electronics or electric equipment in the Directive on Waste of Electronic and Electrical Equipment (European Union 2012). To illustrate, Khor and Udin (2013) find that design for disassembly is linked with extending the use of products through repair, remanufacturing or reconditioning within electrical and electronics sector. Researchers (ibid.) argue that despite this understanding, sector's common strategy is to simply repair or dispose products. This result was based on a quantitative survey conducted in Malaysia.

In this dissertation, the interest for durability considerations stems from the realization that durability of products has been claimed as one of the key issues within a circular economy concept, with even financial incentives planned to incentivize its adoption (European Commission 2017). To start with, term *durability* has its origin in Latin: *durus* stands for 'hard', and *durabilis* 'to last' (Oxford living Dictionaries 2017a).

Ardente et al. (2012, p.17) point out that the way durability is comprehended does influence on the choice of key issues, and how they are prioritized within product development. As an example, activities to enhance the longevity of material properties of a product, or its intended function would both provide an opportunity to enhance product's durability; but, in different ways (Ardente & Mathieux 2014). As illustrated in Figure 5, contradictions may also occur be-

tween choosing durability over products or materials. Put it differently, for instance, a choice of material mixtures and joining techniques would influence the types of activities that are possible for repair or remanufacture, or for the recovery activities at post-use phase. Prendeville et al. (2017) demonstrate how the choice of more durable materials for use phase contradicts with possibilities to recover them later at post-use phase in the case of office chairs. In another example, Parajuly et al. (2016) examine the ways recovery aspects are considered for robotic vacuum cleaners, an emergent product category. Study (ibid.) shows how both the incompatible materials and unaligned wire positions prevent recovery activities for these products in practice.

In the context of companies, Bundgaard et al. (2017) claim that durability aspects may not be seen desirable by the industry that is increasingly seeking to gear toward resource efficiency, although these aspects are increasingly promoted by the EU. Researchers (ibid.) suggest to have durability aspects incorporated into the regulatory frameworks to ensure their implementation, instead of only relying on self-regulatory mechanisms. This argument is based on two case studies in which these researchers examined the integration of resource efficiency measures into the so-called Ecodesign directive (European Union 2009). In contrast, Dalhammar (2016) finds slightly different opinions from industry through qualitative interviews. Namely, although generic positive attitudes toward durability were found, more specific durability aspects, such as warranties, received more negative attitudes.

Moreover, one way to address durability issues concerns understanding of a product's emotional dimensions, or emotional durability (Niinimäki 2011). In this approach, emotional durability aims to establish longer lasting relationship with a product by extending the individual's attachment and satisfaction aspects (ibid.). In a similar vein, Stevels (2016) discusses this alongside the dimension of an emotional functionality aspect with an example: feeling good. A practical example on this aspect is given in a study by Fitzpatrick et al. (2014). This study reports results for a pilot seeking to enhance an emotional attachment for a computer: a tactical pleasure was enhanced by introducing a wooden framed computer. This is of a relevance, as useful lifetime along the use phase may considerably differentiate between aspects of technical and emotional durability (Niinimäki 2011; Fitzpatrick et al. 2014; Stevels 2009; Bakker et al. 2014; den Hollander et al. 2017).

Two environmentally related topics, namely durability and lifecycle, are typically discussed together, although the way they are categorized together may differ. As an example, Pigosso et al. (2013) propose to categorize lifecycle as a management practice, and durability aspects as an operational practice. These operational aspects on durability would include discussion on material or product lifespan extension (ibid.). In contrast, Tecchio et al. (2017) propose to categorize "extend the lifetime" as an example of overall policy goal toward material efficiency. In this proposal, the durability consideration is seen as a topic within the material efficiency. In recent guidelines for implementing circular economy in organizations, durability aspects are similarly positioned as overall goals (The

British Standards Institution 2017). However, as visualized in Table 1 in Publication 3, often durability aspects are regarded as operational ones, and therefore their implementation guidelines are targeted for product developers. Nevertheless, it is argued that addressing these two topics would provide leverage toward strategies enhancing circular economy.

One early indication of implementation levels for circular economy is provided in a survey among 272 sustainability professionals from 151 organizations (BSR & Globescan 2016): approximately one in three considered that circular economy principles had been implemented in their organizations, most notably within product development, as well as considerations for cross-sector collaborations and business models were reported. However, it is not clear what is meant with implementing circular economy core principles in the survey.

To conclude, this section has approached circular economy concept from the interpretative and communicative standpoints postulated by the ecodesign capability framework discussed in 2.3. Moreover, plentiful research exists for supporting circular economy related thinking and practices from the knowledge dimension within the ecodesign capability framework. For instance, recovery of the materials, substances, and the ways to enhance disassembly, are examples of topics that have been in agenda for ecodesign research since the early days (Boks & McAloone 2009; Pascual, Boks, et al. 2003; Vanegas et al. 2018). However, this current research examines further the ways that may enhance the implementation of such activities within product development, and therefore, we now turn to softer side of the ecodesign.

2.5 Theoretical perspectives on human factors in ecodesign

This section details the role of individuals at the micro-level, thus expanding the discussion into human factors influencing the ecodesign implementation. To this end, soft-side of ecodesign emphasizes, among others, a need for a better understanding of personal views and objectives, as well as language and communication (Boks 2006). These are understood as examples of human factors.

One way to discuss this is to apply the three ecodesign capabilities discussed earlier at the meso-level (Please, see 2.3). These three capability dimensions – knowledge, interpretations, communications- are extended to the micro-level with a focus on individuals that are a vital part of accumulating such capabilities. The Figure 7 in the next page illustrates the ways in which these ecodesign capabilities (Lenox & Ehrenfeld 1997), ecodesign implementation framework (Tingström 2007) and selected topics posited by Stevels (2016, p.25) could be positioned together within this research framework.

Applied ecodesign seems to broadly interconnect these three dimensions of ecodesign capabilities -knowledge, interpretation, and communication- as a necessary interplay for implementing environmentally relevant practices within companies' internal value chains (Stevels 2009). Namely, it emphasizes the role between an actual technical understanding of environmentally sound solutions, and the role that an individual's attitudes may have in implementing such practices.

To illustrate this, the main constraints preventing product developers from adopting the use of ecodesign tools are found to include the usability of tools, the ease of understanding them, and the understanding that a given tool should indeed fulfill a requirement set for the task in the first place (Lindahl 2005). If the dimensions of ecodesign capabilities are applied to this example, the following might be conjectured. The first two aspects - sense of usability and easiness - may stem from interpretational aspects, while the last one could be related more to the knowledge dimension, such as training. Namely, according to Tingström (2007), simply launching such tools without training on broader issues linked with the reasoning to use tools would not support their implementation.

Figure 7. Illustration of ecodesign capabilities positioned within the research framework.

One way in which different personal views and objectives may have an influence on ecodesign implementation is their impact on behavior. This may emerge as different behaviors practiced to advance issues internally between so-called proponents and executors of ecodesign (Boks & McAloone 2009; Boks 2006; Handfield et al. 2001). For example, Magnusson and Johansson (2006) examine the different ways in which environmental considerations are interpreted, as well as their impact in practice. They report that those members of the product development project expected to realize environmental considerations into their respective work tasks did not consider environmental considerations to be a requirement, and thereby excluded them. The study (ibid.) shows that one reason for this non-compliance was the lack of translating environmental requirements into corresponding technical requirements, and that they were not considered to be a 'must' requirement in the first place. By applying the ecodesign capabilities to this example, this may be understood to be a combination of the interpretation and communication issue.

Turning to the communication dimension within ecodesign capabilities, this dimension could be further understood through the points raised within the soft-side of ecodesign. Based on a qualitative study within the electronics sector, Boks (2006) posits that a successful dissemination of environmental information within organizations is hampered by the following three issues: a gap between executors and proponents, structural complexities, and an absence of cooperation between departments. Answering these topics in more details might again interlink the dimension of interpretational aspects between these communication issues. For instance, is it a question of incentives to which, for instance, self-determination theory might provide some insights at the micro-level (Graves et al. 2013; Gagne & Deci 2005). Self-determination theory considers incentives applicable to individuals who are not self-motivated, i.e. intrinsically motivated, to act towards a desired direction. Instead, such individuals receive motivation from external, extrinsic, factors, such as receiving incentives (see more in Gagne and Deci 2005). Or, might other types of motivational reasons exist hidden behind it, too?

To answer this, for example, Short et al. (2012) approach sustainable product design implementation issues from the perspective of the theory of risk-aversion. Researchers conducted a quantitative survey among companies in Sweden and in the United Kingdom in order to assess sustainability related practices in product development. Based on their findings, researchers argued that an individual's risk-avoidance might be one of the reasons hindering the emergence of sustainability related practices in product development. This is also reported among the potential barriers to implement circular economy thinking within organizations in a recent interview study (Ritzen & Ölundh Sandström 2017). Similarly, in a company-level study looking at ecodesign implementation, it is found that resistance to change is among the factors that needs be considered along with organizational culture, empowerment and internal communication (Verhulst 2012, p.212).

The study by Short et al (2012) further shows that "own belief" emerged as the third most frequently mentioned reason to engage with sustainable design. In a similar vein, an individual's interest in engaging with ecodesign is raised as an additional item into a framework addressing ecodesign implementation challenges (Dekoninck et al. 2016). This framework by Dekoninck et al. contains categories for strategy, tools, collaboration, management, and knowledge. Researchers add an additional motivational aspect to the category of management based on a case study where the proposed framework was assessed (ibid.).

Furthermore, Boks (2006) reasons that even the emotional aspects might be at play in better understanding the issues of ecodesign implementation. Similarly, the role of emotions has been increasingly studied in order to understand the motivational factors behind the environmentally benign behavior at the workplace in general (Inoue & Alfaro-Barrantes 2015). In addition, one recent interest within the research into emotions includes better understanding the role of positive emotions. Research by Fredrickson (2003) posits that positive emotions broaden an individual's creative and problem-solving capabilities, hence influencing individuals through thought-tendencies rather than action-

tendencies. Amabile et al. (2005) investigate these findings on positive emotions among people working in projects including those working with product development. Researchers conclude that a positive affect broadens the creativity spaces in the sample. To continue from this, it is argued that embracing environmental considerations in a positive context might similarly bring about more environmental benign behaviors within product development, such as enhanced ecodesign practices. An example of a similar type of suggestion is found for instance in McAloone et al. (1998), in which also the role of environmental champions is pronounced.

One way to deepen the interpretation dimension within ecodesign capabilities is to approach it through systems thinking. As mentioned earlier (see 2.3), interpretation capability dimension refers to interpreting environmental considerations so valued that these considerations would be put into practice within the respective work tasks. In systems thinking approach (Sterman 2000; Senge 2006; Forrester 1993), basis for interpretations stems from the mental models. Namely, the way real world is observed to behave is understood to be largely based on mental models which create the perceived structure of a given observed system (Figure 8). These mental models form interrelationships with different factors constituting the system, also called a cognitive web of interdependences (Hämäläinen et al. 2014; Senge et al. 2008). Therefore, when working with systems, such as using system dynamics, the first action could be to seek out to explicate these mental models to the greatest extent possible (Sterman 2000). It is usually recommended to start with mapping topics of interests applying causal loops. Although mapping is based on explicated assumptions at the bivariate association level, it helps to visualize potential larger feedback loops that may demonstrate delayed impacts between explicated variables. For those involved with a such mapping, it would assist in explicating interpretations of a given behavior, and to agree on a shared one (Senge et al. 2008; Hämäläinen et al. 2014; The British Standards Institution 2017; Sterman 2000).

Figure 8 in the next page visualizes the posited influence of these mental models consisting of human factors, such as individual's attitudes, beliefs and values (cf. Senge 2006, p.163; Senge 2008, p.176). Values are understood as the extent of topics considered important by an individual; whereas beliefs are more about the extent of considering true that relationship exist between specific beliefs or topics, such as values. Attitudes are understood as an evaluative approach to various topics on a continuum from favorable to non-favorable. An individual's mental models are assumed to govern the perceived reality, and even actual behavior (Senge 2006; Senge et al. 2008; Hämäläinen et al. 2014). As the Figure 8 illustrates, they are assumed to provide among others rules for decision-making; for instance, in the context of product development, Ford and Sterman (1998) demonstrate that the assumed time to complete a task was comprehended differently by different members in the team. This resulted in a different understanding of the leverage of each stage in product development, which in turn created an overall misunderstanding of the project's task completion rates.

In the context of ecodesign, one relevant interpretation structure could be based on individuals' basic assumptions related to environmental issues. These assumptions may constitute of beliefs on various relationship dimensions between humans and the natural environment. To estimate the extent of these relationships, Dunlap et al. (2000) propose one measure, the New Ecological Paradigm (NEP). This NEP measure seeks to capture the essence of an individual's beliefs on these relationships representing what is called an ecological worldview (ibid.). It taps into these relationships through two broader dimensions: one related to the role of humans influencing the natural environment, and the other one related to the current state of affairs in the natural environment (Lau et al. 2016).

Dunlap et al. (2000) categorize the ecological worldview into five dimensions. These five dimensions range from agreeing with the relationship statements such as the potentiality of eco-crisis, balance of nature, or limits of growth, to the potential dominant role of humans over nature. Agreement with such statements are anticipated to expose an individual's core beliefs on the interplay between the natural environment and humans. Although these items are stated on a generic level, they are expected to also potentially relate to more specific environmental topics (Stern 2000; Stern et al. 1995). In addition, it is anticipated that they evolve gradually in ceaseless interaction with constrained external environment (ibid.). In this dissertation, ecological concern denotes these generic ecological beliefs.

Figure 8. The role of mental models (Stermann 2000, p.19).

Although NEP's potentiality to deepen understanding on the implementation issues within the soft-side of ecodesign may seem insightful, studies have provided mixed results measuring relationships between actual behavior and the NEP within companies in general (Publication 3). Furthermore, no published results are found on the potential relationships between the NEP, and people working in product development. On the other hand, the aforementioned results by Short et al. (2012) show some indication in this direction, although the NEP measure was not used. In addition, it is argued that the NEP might enable a deeper understanding of the differences between the proponents and non-proponents. As an example, Lau et al. (2016) report findings on what researchers

call “humans over nature”, as a latent structure among project managers when investigating NEP measure in Malaysia.

Based on this discussion, it is argued that an improved understanding of perceptions at the micro-level may clarify the underlying thinking premises among others related to issues surrounding enhancing circular economy within product development. Individual mental models are seen to govern applied language, for instance, around ReX strategies; moreover, gaining an opportunity to better explicate them through discussions might also allow their expansion (Senge 2006; Senge et al. 2008). As an example, the way an individual interprets a given context related to ReX strategies may be understood by the language the individual uses, including terms and arguments applied.

To elaborate the use of language more broadly, the following example is provided. As the intention of a product development project is to bring a new product to the market, it is plausible that this intention is often framed as a brand-new product within discussions in the product development teams. However, what if the term used in these discussions would be a *brand-old* product instead of a brand-new? This term might be associated closer to the ecodesign thinking similarly to “brand-renewed” (Hood 2016). This example seeks to envision the way a positively laden impetus in language might provide different stimulus in the context of product development inclined to novelty (O’Hare 2010, p.42). Similarly, a positively sounding term *presource* has been suggested to denote “obsolete products waiting for recovery” (den Hollander et al. 2017).

It is argued that using positively laden terminologies might provide inspiration to broaden thinking alternatives of the lifecycle phases towards which a forthcoming product could be targeted. This coincides with a recent broader discussion on circular economy, in which it is also argued that perhaps the main novelty in current discussions on circular economy relies on seeking to change “attitude of mind”, among others about “moving from the idea of consuming” to using of materials (Ashby 2016, p. 212, 221).

This section has discussed ways in which examining individuals (see also Lindahl 2005) provide complementary understanding to the company level research (Verhulst 2012) on human factors potentially influencing ecodesign implementation. Lozano (2014) posits that several research levels are indeed necessary to attain sustainability. These levels include individuals, teams and organization that all interact and influence each other. In systems thinking, it is postulated similarly that individuals, as part of systems, both influence and are influenced by the various systems they are part of (Hämäläinen et al. 2014).

Individuals working in the product development teams are constrained by their own mental models, in addition to their organizational constraints. On the other hand, individuals may also have a possibility to influence organization among others through their respective teams (Lozano 2014). An examination of these aspects based on among others organizational and behavioral theories (Brones et al. 2017) could deepen the understanding of ecodesign implementation issues. For instance, organizational policies may be interpreted by individuals either as impeding or enhancing the consideration of environmental topics

within their work, regardless of communication from management, or the availability of tools or methods (Lenox & Ehrenfeld 1997). To conclude, this section set out to discuss human factors within soft-side of ecodesign. It was discussed how internal value chains are comprised of individuals with their interpretations of acceptable environmental benign practices; and as mentioned earlier, such interpretations may influence more than anticipated (Stevens 2009; see also Kirchherr, Hekkert et al. 2017). The potential extent of such influence is explored empirically next.

3. Research methods and data

This chapter discusses the research methods and data used in the dissertation. More detailed information on these topics can be found in the respective publications located at the end of this dissertation.

3.1 Research methods

In this dissertation, the overall research approach is descriptive with the purpose of exploring the selected characteristics of enhanced ecodesign implementation practices, their extent and potential relationships. The actual research methodology (Malhotra 2004) iteratively applied is as follows. It begun with formulating the research problem and objective as well as the approaches to address them by also formulating the research questions. It then moved to choosing underlying theories through a literature review, and selecting a research design. The overall research approach suggested that quantitative research might be appropriate (Creswell 2003, p.93). Next, chosen research methods were applied. The types of research methods applied in this dissertation are a survey and content analysis. Publications 1 and 3 are based on the survey, and the Publication 2 on the content analysis.

The methodological approach applied in Publication 1 follows broadly the mental database approach by Forrester (1993). In this approach, the observable world is assumed to consist of three levels. The overall level consists of observed policies and structures, the middle level is about perceived expectations about the topic or behavior in question, and the third level refers to actual behaviors.

Using a survey as a research method provides a way to observe a real-world phenomenon through the perceptions that respondents offer when they answer the survey. In this research, the observer is an individual at micro-level perceiving these ecodesign practices. After conducting the survey by collecting the data, data is prepared for analysis before the results are presented. By applying this type of empirical approach quantitatively, it is possible to both extend and validate constructs from similar research, as well as test new constructs. This research design contributes to the knowledge by studying individuals as the unit of analysis, which allows assessment of relationships with selected attitudinal factors, and ecodesign practices (Table 1 in Publication 1).

Content analysis is a systematic research method enabling the investigation of existing content, for example visuals or texts, for potential trends and patterns of the observed phenomenon (Krippendorff 2004). It is regarded as an unobtrusive research method enabling researchers to examine phenomenon of interest that might be otherwise inaccessible. For instance, researchers may infer awareness of a concept by simply assessing its existence or absence in the given data. (Ibid..) Its benefits also include being able to access the original source as many times as needed in contrast to case studies or surveys. For these latter forms of inquiries, there are usually records used to store answers that are bound by questions asked, and the way they are asked (Tangpong 2011). Although the data may initially be unstandardized due to its qualitative characteristics, content analysis provides a systematic way to compile results into a format allowing both qualitative and quantitative analysis to be derived from the data (Krippendorff 2004; Mahapatra et al. 2015; Tangpong 2011).

In Publication 2, content analysis is applied as the research method. Content analysis comprises of designing, collecting, preparing data for the analysis, and the actual analysis. Analyzing sustainability reports with this research method has now emerged as an insightful way to gather data. Today, more standardized sustainability reporting frameworks, for example from Global Reporting Initiative (GRI), are being applied by companies worldwide (KPMG 2015; Tangpong 2011). However, it has seldom been used to quantitatively assess ecodesign practices (see Table 1 in Publication 2). Therefore, this research contributes to the literature by exploring applicability of this type of research method to assess ecodesign practices in companies. Guidelines from Krippendorff (2004) and Tangpong (2011) are iteratively applied in Publication 2, in which six hypotheses are derived from the research questions posed. The actual steps for content analysis include the collection of data, their codification, and analysis (Weber cited in Tangpong 2011).

As a methodological approach, Publication 3 follows the concept of classic *causas* based on the Aristotelian way of inquiring (Saarinen 1997, p.54-56), as one methodological approach to frame the discussion from various perspectives. The *causas* applied are *causa materialis*, *causa efficiencis*, and *causa formalis*, while *causa finalis* is excluded. In a way, this seeks to provide relationships in a format that supports observing the world with elements that the author considers an important focus of attention (Weick 1989).

3.2 Data and statistical analysis

This section introduces the types of data used in the dissertation. A survey is used to gather primary data for the Publications 1 and 3. In Publication 2, data is primarily derived from sustainability reports. Additional data is gathered from the CDP (formerly known as Carbon Disclosure Project) website for one item to assess external environmental performance. In both cases, the judgemental non-probability sampling (Malhotra 2004, p.320) was applied to gather data.

Data analyzed in Publications 1 and 3 was collected with a same online survey allowing respondents to reply anonymously between June and August 2014. Respondents' belonged to the chosen sampling frame, The Federation of Finnish Technology Industries member companies that present a range of industries, and approximately 50 percent of Finland's research and development investments, and exports in 2013 (Teknologiateollisuus 2014). A judgmental nonprobability sampling was based on drawing these employees from the association's environmental topic-related mailing lists and working group. These respondents, totaling 51 in Publication 1, and 45 in Publication 3, work in larger manufacturing companies with mainly business-to-business customers. When compared with the sampling frame, these companies are biased toward metals and mining industries, and larger sized companies. The respondents themselves were highly educated, and they represented various functions. A more detailed description of the sample characteristics may be found in Publication 1, Table 2.

The level of analysis in Publication 2 is at company level with the purpose of assessing adoption of selected ecodesign activities at the meso-level. Assessed companies are part of the ICT sector with a bias toward manufacturing electronic and electric equipment and components, due to the sampling criteria followed in order to better answer the research objectives set for the paper. The final sample consists of 43 companies, of which 17 companies are also found in Pascual, Stevels et al. (2003) when taking into account also the consolidated companies. Companies in the final sample are large, international companies with experience of environmental issues or sustainability at large, often for more than 10 years. The collection of the companies' most recent sustainability reports, as sampling units, occurred in two waves in 2015; in July, and in October. Details of the companies are available in the Appendix found at the end of Publication 2.

A statistical analysis is conducted with SPSS software for both samples. In Publication 2, content analysis was conducted using Atlas.ti and Adobe document software before a statistical analysis. Descriptive data analysis is mainly applied due to the nature of the data being mostly nonparametric (Malhotra 2004; Hair et al. 2010). Bivariate relationships are assessed with Spearman correlation (r), Fisher's exact two-sided test, and the Mann-Whitney test (U-test). Additionally, partial correlation is applied once. The scale for the ecological worldview is derived by using factor analysis. For analysis, a threshold of 0.05 for the probability value (p-value) is applied for a significance of result.

3.3 Variables

This section broadly describes the variables, or items thereafter, used in the survey and the content analysis. The exact questions asked in the survey can be found in the Appendix 2, as well as from the appendices for Publications 1 and 3.

Survey items were derived from extant research to the furthest possible extent, and new items were formulated if not found from the extant research. Before

conducting the survey, the survey was pre-tested by four persons. Webropol (<http://webropol.fi>), an online survey platform, was used to conduct the survey.

The survey contained in total 35 questions divided into five sections in English. These sections covered items including background information from the company and the respondent's work (9 questions), generic product development topics (6 questions), integration of environmental considerations into product development (11 questions), company level sustainability related topics (6 questions), and personal information (3 questions). At the end of the first section, a validation question was asked, and if a respondent answered "Never or almost never" to the validation question regarding the frequency at which a respondent usually worked with product development, then the respondent was moved forward to the remaining two sections.

Selected potential circular economy considerations in Publication 3 were mainly derived from the so-called EUP Directive (European Union 2009), the Ten Golden Rules (Luttropp & Lagerstedt 2006), and from the design for environmental guidelines and principles (Telenko et al. 2008). The 15 items assessed ranged from renewable and recycled materials to the considerations of durability, as well as metal and plastic recovery.

For the research question three items to describe perspectives from micro-level were included. These were attitudinal questions (enjoyment, easiness), norms (perceived support from top management and from colleagues), background information about the respondent as well as individual's values related to environment using the NEP scale, and assessment of importance for the environmental considerations.

The NEP scale (Dunlap et al. 2000) consists of 15 items that were aggregated to a summated scale by reversing the positively phrased items, and retaining the negatively stated odd items as is. In Publication 1, this summated scale was used. In Publication 3, the nature of the data was examined further to derive a measure, an ecological concern that would present findings from that data, as also suggested by Dunlap et al. (ibid.). This approach sought to accommodate the debate on whether the NEP scale should be applied as a multidimensional or unidimensional scale (Amburgey & Thoman 2012; Hawcroft & Milfont 2010).

In addition, multiple modes of answering were applied in the survey, such as Likert or ordinal scales, forced closed lists, and open answers. Furthermore, to ease the cognitive load, simpler questions were asked first and having brief definitions for the main terms used, such as lifecycle or environmental considerations. Respondents also received an option to choose "Don't know", "Not applicable", or "Choose not to answer" to those questions which may have been considered more ambiguous.

For the purposes of grouping, the following categorizations were used for the items in the survey. In Publication 1, summated scales for early product development and ecological worldview were divided into two based on averages. Then, the top two response alternatives were used as the categorization. An example would be putting into one group responses with "Very often" and "Often", or "Strongly agree" and "Agree". Then, a similar type of response alternative was

a grouping rule for four items. These were the role of environmental considerations, location of responsibility, sustainability-based incentives, and formal management processes for product development.

Items in the content analysis for Publication 2 were also derived from literature to the furthest extent possible (Table 8). These items were evaluated in two ways: examining occurrences of selected terms, and evaluating the content for its quality (Krippendorf 2004; Lülfs & Hahn 2014). The former approach is assumed to reveal an awareness of an assessed term. The term's exclusion or inclusion in a given sampling unit is an equally important outcome derived from the content analysis (Krippendorf 2004). The latter approach refers to evaluating the quality of reporting assessed (Lülfs & Hahn 2014). It was applied to two items: evaluating internal environmental performance, and the environmental quantitative targets. Following the approach adopted by Pascual, Stevels et al. (2003), quantitative environmental targets were judged to conclude the type of targets they were. Namely, whether they referred to product development processes, products, or product portfolio. Then, the target should comprise of a measurable element and contain information on the time horizon. It may be either a relative or an absolute one (Issa et al. 2015).

Table 8. List of items assessed in the content analysis (adapted from Publication 2).

Level of assessment	Main items assessed (* denotes that different endings of the word were accepted)
Occurrence of term	<ul style="list-style-type: none"> • Ecodesign claims (Montabon et al. 2007; Pascual, Stevels et al. 2003): Ecodesign, Design for environment, product stewardship, green products, green devices, etc. • Terms: Circular economy; Lifecycle/life cycle/ life-cycle; Durab*, longevity; Reus*, repair*, refurbish*, recondition*, remanufacture*; Disassembl*; Dismantl*
Quality of reporting	<ul style="list-style-type: none"> • Environmental quantitative targets for products (Bjørn et al. 2017; Montabon et al. 2007; Pascual, Stevels et al. 2003) • Responses to reclaimed products G4-EN28 categorized into two: no information or narrative vs. partial or full quantitative information • Inclusion of environmental targets in CEO messages

Turning to two environmental performance items, internal environmental performance was assessed with the capability to report information to the indicator G4-EN28, "Percentage of products sold and their packaging materials that are reclaimed by category", in GRI version 4 Guidelines (Global Reporting Initiative 2013, p.129). Completeness of responses to this indicator was evaluated. Consequently, responses were categorized into two groups. Responses were coded as 0 for those companies that did not answer to this indicator or reported information narratively. Code 1 was used for those responses that were numerical for both reclaimed packaging or products, or either of them. Quality of this information was not, however, analysed further.

For the external performance, the ranking in the CDP was assessed for the reporting year 2014. CDP ranks companies for their progress performance on, and disclosures about their greenhouse gas mitigation activities. The progress is ranked by dividing companies into five performance bands. These five bands were aggregated into two groups based on the following classification: group coded as 1 consisted of companies ranked as A and B, and group coded as 0 consisted of companies that were ranked C, D and E.

4. Results

This chapter reports the overall results from Publications 1 to 3 related to research questions posed for this dissertation.

4.1 Ecodesign practices within product development

This section provides an overview of the results related to the first research question. Results are derived from Publication 1, 2, and 3. First, the context of ecodesign practices are compared to those of generic product development practices in Publication 1. Then, in Publication 2, the level of environmental quantitative targets for products are analyzed, while estimates on the extent of lifecycle thinking are found both in Publications 2 and 3.

In Publication 1, the perceived level of formal management processes for product development in general is found to be established within respondents' product development contexts. While 76 percent of respondents perceived it thus, the remaining 20 percent reported that the generic product development processes are, however, informal, but understood.

In contrast, 49 percent reported that environmental considerations are formally managed within the product development processes, although an additional 44 percent viewed them as being informally in place. In addition, the results support the association between having formally managed product development processes in general, and the inclusion of environmental considerations embedded in these processes. Namely, those respondents that considered generic product development processes to be managed formally, were also significantly more likely to also perceive that environmental considerations are formally managed within product development processes. More specifically, 65 percent of those respondents reported so compared to 35 percent of them reporting otherwise (p-value 0.000).

In Publication 2, the level of quantitative environmental targets for products within the ICT sector's leading companies in environment was assessed. Overall, almost all the companies asserted their considerations of environmental issues in their product development, albeit the terms used to describe these activities varied considerably. When the extent of the commitment to quantitative targets was assessed, slightly over half, or 56 percent ($n=24/43$), of the companies communicated having such targets based on their sustainability reports. Most often these were related to the energy-efficiency of products during use,

although seven companies provided quantitative environmental targets also for their reclaimed products. Furthermore, companies with a longer history in sustainability reporting were significantly associated with disclosing quantitative environmental targets for products (p-value 0.001).

Returning back to the survey results reported in Publication 1, Figure 9 below illustrates the perceived role of environmental considerations in product development contexts which respondents represented. Close to 40 percent of the respondents perceived that s/he works in a product development context in which environmental considerations are understood either to be a requirement (13%) or mandatory checklist (25%). Interestingly, those respondents with such perceptions were also more likely to consider that management processes for environmental considerations were more formal than not. More specifically, 77 percent of these respondents perceived environmental considerations as being formally managed within product development, compared to 23 percent of them perceiving otherwise (p-value 0.006).

Figure 9. The types of roles assumed for environmental considerations in product development (Publication 1).

Lifecycle thinking is one topic considered to be a vital aspect of the ecodesign. The awareness of lifecycle thinking reaches 84 percent among the companies from the ICT sector (Publication 2). In addition, it is associated with the quantitative environmental targets for products. In Publication 3, 89 percent of respondents working with product development perceived that lifecycle has been considered to an extent (from the scale 1-7: responses with 4 or more) in their typical product development during the previous 12 months. Moreover, in Publication 3, associations are detected with lifecycle thinking and a few ecodesign practices. It is reported that an increased extent of lifecycle thinking is associated both with the perception that environmental considerations are managed formally within product development (U-test p-value 0.006), and that their role is perceived to be more of a mandatory checklist or a requirement (U-test p-value 0.012).

The phases used to describe product development process were expected to be customized to fit companies' contexts. Indeed, different phases were described in open answers. However, the examined product development phases were identified to have been frequently (often/very often) applied by the majority of

respondents (Publication 1), with the exception of the embodiment phase. The three phases which were most frequently applied include setting the functional requirements (73%), detailed design (76%), and conducting testing and refinement phases (78%). Nonetheless, respondents reported less frequent inclusion of environmental considerations within the examined product development phases. According to 44 percent of the respondents, they were frequently applied in the four following phases: planning and task clarification, functional requirements, testing and refinement, and considering the production. Additionally, 36 percent of respondents perceived that environmental considerations are frequently applied in the conceptual phase.

Next, a combined scale was investigated related to the earlier product development phases; namely, task clarification and planning, functional requirement, and conceptual phases. A rough half, or 58 percent of respondents considered that all three earlier product development phases were frequently applied in general. However, this perception dropped to 27 percent, when the frequency of the inclusion of environmental considerations were reported at these same phases. Nevertheless, these two scales were associated with each other: frequently applying these early phases in general is also associated with including environmental considerations frequently within these phases (69% vs. 31%, p -value 0.039).

While perceived formal management processes for generic product development are positively associated with the frequency of applying the generic early product development phases, no such bivariate relationship is detected when environmental considerations are included within these two potential practices (p -value 0.767). In addition, no direct association is detected with frequently including environmental considerations in early product development phases and the role of environmental considerations as a requirement or mandatory checklist (p -value 0.135).

Moving forward, close to half the respondents (47%) observed that the role of environmental considerations is at par with quality in their product development context. In addition, those with such observations were also more likely to perceive environmental considerations to be a mandatory checklist or requirement than those not observing so (71% vs. 29%, p -value 0.016), and that environmental considerations are frequently included in the early product development phases (p -value 0.016). In addition, the perceived extent of lifecycle thinking was also positively associated with perceiving environmental considerations to be at par with the quality (Publication 3, r 0.415).

Furthermore, there was interest to explore whether the use of tools or methods to consider environmental topics in a respondent's work had provided any benefits for the respondent at the micro-level. However, it should first be noted, that 24 percent of respondents ($n=11/45$) actively admitted that, during the previous year, s/he had not used any such tool or method. For those who did report some benefits, the two main benefits were that use of such tools and methods allowed to fulfill a requirement that had been set for a given product development phase (42%), and to share information with others (29%).

The perceived benefits of tool's use to fulfill a specified requirement is associated with the perception of more established ecodesign practices. For instance, it is positively associated with formal management to include environmental considerations in product development: namely 74 percent of those respondents considered it thus, compared to 26 percent of them considering otherwise (p-value 0.007). Moreover, the role of environmental considerations is perceived as a requirement or a mandatory checklist (p-value 0.029). Likewise, respondents who observed this benefit are more likely to report that environmental considerations are frequently included in the early product development phases (p-value 0.014).

In the sample, the overall organizational readiness through communicational aspects is perceived to be at a high level. A clear majority of respondents reported the existence of formalized environmental policies (94%) and environmental objectives (90%). Moreover, 79 percent of respondents reported that their companies have environmental requirements for suppliers. Besides, the majority of respondents, or 61 percent, held the view that top management supports the consideration of environmental topics at large, similarly to the perceived extent of support from colleagues at 59 percent to include environmental considerations into one's work. In contrast, actual supporting practices show a less common prevalence. Namely, 51 percent of respondents considered that it is easy to find environmental information on environmental issues within a company, whereas 49 percent believed they had received enough of training on environmental topics.

Furthermore, support from top management does not increase the likelihood of environmental considerations being regarded as a requirement or mandatory checklist, nor that management of environmental considerations would be regarded as formal in product development. In contrast, the perceived level of training was associated with considering the environmental considerations to be a requirement or a mandatory checklist (55% vs. 22%, p-value 0.033). On the other hand, perceived support from top management increased the likelihood of reporting that environmental considerations are included more frequently within the functional requirements (75% vs. 25%, p-value 0.034), and the prevalence of sustainability-based incentives (68% incentives vs. 32% no incentives/else, p-value 0.001). Moreover, a significant association was found with perceiving the existence of sustainability-based incentives and frequent inclusion of environmental considerations in the early product development phases (64% vs. 36%, p-value 0.016).

4.2 Linking selected circular economy considerations with other ecodesign practices

Publication 2 presents results on exploration of the ways the role of quantitative environmental targets for products may be associated with circular economy in terms of terminologies applied. In Publication 3, the prevalence of selected circular economy considerations along the three lifecycle phases are assessed, as well as their possible associations with other ecodesign practices.

Within the ICT sector sample in Publication 2, the term “circular economy” was just emerging with six companies, or 14 percent ($n=6/43$), mentioning it in the assessed sustainability reports. This term was mainly placed alongside explanations of companies’ aims to use more recycled or recyclable materials, or alternatives for their customers to recycle or reuse their products. As depicted in Table 9 below, somewhat low frequencies of occurrences were detected for the selected terms to extend the use phase. Although most companies mentioned reuse, it was less often mentioned what was meant by this term. In addition, terms for describing activities along reuse differ among the companies also suggesting various interpretations for their actual meanings. As an example, one company uses two terms - “refurbished” and “remanufactured”- interchangeably in the analyzed sustainability report.

Table 9. Prevalence of terms found in the sustainability reports (adapted from Publication 2).

Phase	Awareness of selected terms (n=43)
	Circular economy 14%
Pre-USE	Ecodesign claims 93% Lifecycle 84% Durability 35%
USE	Reuse 93% Repair 44% Refurbish 30% Repurpose 2% Remanufacture 23% Not using any of terms: repair, refurbish or remanufacture 37% Disassembly 26%
Post-USE	Recycle 98% Dismantle 21%

Furthermore, results in Publication 2 suggest that intertwined activities exist between the environmental quantitative target setting for products, and the possibilities of extending the product’s use phase within the ICT sector. For example, companies that mentioned remanufacturing activities are more likely to have quantitative environmental targets for products in place (p-value 0.026). In contrast, no such association is detected with awareness for repair or refurbish. In addition, those companies that mention either durability or lifecycle in their sustainability reports are more likely to report quantitative environmental targets for their products (p-values 0.026, and 0.033, respectively).

Environmental performance was assessed via two items. Being sufficiently mature to be able to communicate on reclaimed product or packaging flows is found to be associated with quantitative environmental targets for products. Namely, eighty-one percent of those companies disclosing this type of quantitative information are more likely to also have quantitative environmental targets for products in place, as opposed to 19 percent otherwise (p-value 0.013). Both mentioning durability and repair are associated with companies disclosing quantitatively about their product or packaging flows as well (p-value 0.046, and p-value 0.025, respectively). In contrast, no such relationships were detected with mentioning refurbish or remanufacture activities. Another proxy for environmental performance assessed was company ranking in the CDP. This item is also found to be associated with quantitative environmental targets for products (p-value 0.027), but not with other ecodesign practices assessed.

Furthermore, the relationships with ecodesign practices provided interesting results for durability considerations in Publications 2 and 3. In Publication 2, occurrence of the terms “durability” and “lifecycle” were not associated with each other in the sample from the ICT sector (p-value 0.391). Neither were considerations for durability within typical product development projects associated with the extent of lifecycle thinking in Publication 3 (p-value 0.451). To further examine the prevalence of durability, the following results emerged. In the ICT sector sample, approximately 35 percent of companies used the term “durability” in their sustainability reports (Table 9). In Publication 3, the level of perceived durability considerations revealed 29 percent of respondents agreeing strongly or mildly that durability had been considered within typical product development projects.

Continuing with the survey findings from Publication 3, relationships with 15 selected circular economy considerations were assessed in the context of typical product development projects. Perceived considerations for recycled and renewable materials were two topics that correlated the most from these 15 items (r 0.788), followed by ease of material separation and labelling (r 0.541). Then, the reporting of lifecycle thinking is found to correlate positively with five items, among others, with perceived increased use of recycled materials (r 0.336) and minimizing the use of materials (r 0.373).

The perceived durability considerations are found to correlate with four items: positively with perceived considerations for renewable (r 0.400) or recycled materials (r 0.326), and stand-by energy (r 0.333). It was also found to negatively correlate with reliability (r -0.391). On the other hand, reliability considerations also correlated negatively with perceived considerations for recycled materials (r -0.379). In contrast, considerations for reliability correlated positively with perceived considerations with ease of disassembly (r 0.327).

Then, perceived considerations for durability were examined with ecodesign practices with little success. They were not associated with perceived formal management for environmental considerations in product development processes nor with reporting environmental considerations to be a requirement or a mandatory checklist. In addition, no significant relationship was detected with perceived durability considerations and with considering environmental topics being at par with quality. In a similar vein, considerations for durability did not correlate with the perception of having received enough of environmental training or with perceived ease with which to find environmental information. In contrast, perceived considerations for durability was found to correlate with increased frequency to include environmental considerations at task planning and clarification phase (see Table 10).

Furthermore, few other selected ecodesign practices were associated with these circular economy considerations in typical product development projects. Perceived formal management processes for environmental considerations in product development were associated with two topics assumed to provide leverage especially during the post-use phase: minimizing hazardous substances, and increased considerations for the recovery of metals (U-test p-values 0.043 and 0.004, respectively). The perception that environmental considerations are

regarded as a requirement or mandatory checklist is associated with perceived considerations for the recovery of metals or plastics (U-test p-values, 0.015 and 0.008, respectively). Furthermore, one topic correlates with the knowledge dimension of the ecodesign capabilities. Namely, the perception of having received enough of environmental training correlates with considerations for the recovery of metals in typical product development projects (r 0.434). Table 10 below depicts those selected topics that correlate with the environmental considerations in the early product development phases (Publication 3).

Table 10. Correlations between selected circular economy considerations and phases in the early product development (Please, see Appendix 2 for exact wording in the survey).

Environmental considerations frequently (often/very often) in...	
Task clarification and planning	Durability considerations (r 0.343) Reusability considerations (r -0.342)
Functional requirements	Reliability (r 0.362) Ensuring material compatibility for recovery (r 0.415) Recovery of plastics (r 0.331)
Conceptual design phases	Minimizing material usage (r 0.330) Ease of disassembly (r 0.378) Ease of separating materials (r 0.388)

Assessing the ways these selected circular economy considerations to be at par with quality provided interesting bivariate relationship patterns. Specifically, the extent of considering environmental topics being at par with quality correlates with eight out of 15 items assessed with the highest correlations detected with perceived increased recovery of plastics (r 0.502), and minimizing the use of materials (r 0.508). It also correlates with the increased extent of lifecycle thinking (r 0.415). However, perceived considerations for durability, as one of the focus items in the Publication 3, is among those uncorrelated items.

4.3 Role of selected human factors in ecodesign practices

This section presents results for the selected human factors that were examined in Publications 1 and 3. While Publication 1 contained six items assessed in this context, Publication 3 examined the ecological concern.

The responsibility for environmental considerations provides insight to the way environmental considerations are embedded in the product development. Based on the survey results in Publication 1, in overall there is no one solution on the way this is organized for the uptake of environmental considerations in typical product development projects. However, most often environmental considerations were perceived to be in the hands of the product development, by 39 percent of respondents perceiving it thus. This is followed by other business functions (25%), sustainability or environmental function (20%), and quality or health and safety functions (16%).

Interestingly, the extent of the perceived formalized management processes in product development seemed to have the following associations with the respondents' functional area, and with the location of responsibilities. Specifically, 65 percent of those respondents working in product development or other

business units are more likely to think that processes are more formal to manage environmental considerations in product development, compared to 36 percent of those respondents working in environmental, quality or sustainability related functions (p-value 0.075). In addition, 89 percent of those respondents that perceived the responsibility for environmental considerations to reside in the hands of product development or other business functions were more likely to report that product development in overall is managed formally (p-value 0.022).

In Publication 1, the role of a few attitudes was explored in relation to the environmental considerations within product development. Two attitudes were found to have significant relationships with the frequency of including environmental considerations in the early product development phases. Namely, those respondents that considered it important to include environmental considerations into one's work or those respondents that enjoy doing so are more likely to notice increased frequency of including environmental considerations at the task clarification and planning phase (p-value 0.012, and p-value 0.035, respectively). Similarly, these two attitudes are associated with perception of increased frequency to include environmental considerations at the conceptual phase (p-value 0.004, and p-value 0.012, respectively).

Interestingly, only the attitudinal item on easiness to include environmental considerations in one's own work is marginally significantly associated with the respondent's organizational background. Namely 25 percent of the respondents from product development or other business functions considered it to be thus, compared to 56 percent of respondents representing sustainability, environment, or quality functions (p-value 0.067, $n=45$). However, this item does not increase the likelihood of reporting inclusion of environmental considerations in the product development practices examined.

Perceived norms reveal the following types of relationships. As mentioned earlier, perceived support from top management is associated with frequency to include environmental considerations at the functional requirements. Moreover, the perceived support from top management is positively associated with the enjoyment of including environmental considerations into one's work (p-value 0.002, $n=51$). In contrast, those respondents perceiving support from colleagues to include environmental considerations into one's work are more likely to report perceived increased frequency to include environmental considerations at two later phases: detailed design (54% vs. 19%, p-value 0.030, $n=45$), and when considering production phases (63% vs. 24%, p-value 0.016).

Publication 3 focused on the extent of ecological concern, and its potential relationships with assessed ecodesign practices, and selected circular economy considerations. First, the overall result is that the extent of ecological concern was found to be high: with an average 3.854 on a scale from one to five. The result does not differentiate significantly based on background factors: respondents' functional background, education nor age group.

Furthermore, potential relationships between ecological concern and awareness of selected ecodesign practices were assessed. Both Publications 1 and 3 show the ways in which the role of ecological concern is related to the overall

awareness of environmental considerations within product development. Using all the 15 items of NEP in Publications 1, 79 percent of respondents with more increased ecological concern than average were more likely to perceive that inclusion of environmental considerations in product development is formally managed, versus 27 percent of respondents with below the average ecological concern considering it so (p-value 0.001). In Publication 3, seven items constituting the ecological concern scale similarly provide a significant positive association with the formally managed product development processes for environmental considerations (U-test p-value 0.026). However, related to other assessed ecodesign practices, no significant relationships were detected. Nevertheless, a significant association is detected between ecological concern and the perception that it is easy to find information on environmental topics (r 0.464) in Publication 3.

Publication 3 continued to deepen the analysis with the ecological concern and its potential relationships with selected circular economy considerations. First, the perceived extent of lifecycle and ecological concern were not found to correlate with one another (p-value 0.711). Instead, significant correlations were found with the following six topics out of the 15 items examined. Ecological concern correlated positively with the perceived considerations for durability (r 0.313). Then, ecological concern correlated significantly with the awareness of increased considerations for the materials that are renewable (r 0.405) or recycled (r 0.396), recovery of metals (r 0.410) or plastics (r 0.327), and ease of material separation (r 0.348). On the other hand, the one item on spaceship correlated significantly with three items: considerations for durability (r 0.333), recycled materials (r 0.351), and the material compatibility (r 0.343).

The potential role of ecological concern mediating the awareness of selected topics applied in the typical product development projects was further explored as well. Namely, it is assessed with considerations for durability, and two highly inter-correlated environmental topics: recycled and renewable materials. Partial correlation provided interesting results. When the mediating role of ecological concern is removed from the relationship between the perceived increased considerations for the recycled materials and durability, this correlation first found significant turned into non-significant. However, the relationship remained at a significant level between perceived considerations for renewable materials, and durability. Moreover, the one item on spaceship followed the same pattern in this.

5. Discussion

This chapter discusses the results by reflecting the three research questions posed with the literature. The chapter ends with describing the limitations of the research.

5.1 Research question 1: Are there significant associations between ecodesign practices?

Although an increased interest toward ecodesign spans more than two decades, it remains the position in this dissertation that environmental considerations are not just yet mainstreamed within companies' product development practices. In other words, not all assessed ecodesign practices seem to be dominantly in use. However, indications of a progress have also been discovered. This argument is based on empirical evidence using two samples which both are assumed to represent pro-active companies regarding environmental issues. One sample represents employees' perspectives at the micro-level, and the other relies on perspectives from the meso-level derived from sustainability reports.

Observing the overall level results in Publication 1, the results seem to be broadly within the same range with studies such as Barczak et al. (2009), Short et al. (2012), and Lindahl (2005) on the perceived level of formal management processes for product development with 76 percent of respondents agreeing with this perception. For instance, Barczak et al. (2009) report this to be at the 69 percent. But, less agreement is detected regarding the formality level of environmental considerations in our sample: just about half, or 49 percent of the respondents reported this. However, of those respondents that perceive formal management processes to exist in product development, 65 percent perceived that environmental considerations are formally embedded into these processes. On the other hand, lifecycle thinking, as such, is reported to be at high level in this sample from people working with the product development.

By separately investigating product development phases it is possible to go beyond the overall level into more practical issues (Boks 2006). A deeper understanding of the actual practice may evolve as well as its potential related issues. Interesting indicative comparisons are found with the study by Deutz et al. (2013) and our study, although the differences in research constructs should be acknowledged. Namely, the results were well aligned with findings to the extent of the perceived level of frequency of having the following product development phases in place: functional requirements (67% in Deutz et al. compared to

our result at 73%), conceptual phases (58% vs. 56%), and detailed design (73% vs. 76%). However, none of the separate product development phase are perceived to contain frequently environmental considerations by over 50 percent of the respondents. This research confirms the finding by Deutz et al. (2013), although the extent of results differs regarding the frequency of including environmental considerations within these phases.

The early inclusion of environmental considerations into the product development is suggested for their better leverage (Deutz et al. 2013; Petala et al. 2010; McAloone et al. 1998). This was examined in this research by assessing the frequency of their inclusion in the early product development, such as functional requirements, and assessing the perceived role that environmental considerations hold in the respondent's product development context. Indeed, results indicate that room for improvement exists for perceiving environmental considerations as a requirement or their frequency during product development phases. In other words, the role of environmental considerations perceived as a requirement or mandatory checklist is found to be at 38 percent of respondents' considering it thus. Hence, albeit the sample representing people from assumingly more environmentally oriented organizations, environmental considerations are not yet perceived to be a requirement by the majority of respondents. However, 44 percent of respondents perceive a frequent inclusion of environmental considerations during the task clarification and planning phases (43 % in design briefs in Deutz et al. 2013) and functional requirement (45% in *ibid.*), and 36 percent for the conceptual phase (50% in *ibid.*).

In addition, the frequency of including environmental considerations at the early product development phases was related to providing sustainability-based incentives. As such, this result might also indicate that respondents in the sample were not self-motivated by the environmental considerations (Gagne & Deci 2005; Graves et al. 2013). However, this was not specifically assessed.

Quality aspects are assumed to be intertwined with ecodesign (Johansson & Sundin 2014). One way to approach this interconnectedness is to assess to what extent environmental considerations are on a par with quality (Handfield et al. 2001). Roughly half of the respondents perceive that in their product development contexts, environmental considerations are regarded to be equal to quality (see Figure 10). These results further show that perceiving it so is associated with other ecodesign practices, such as considering environmental considerations to be a requirement or a mandatory checklist, or that environmental considerations are taken into account in the early product development phases.

In Publication 2, the extent of target settings, as a proxy for more mature ecodesign practices, was assessed within the ICT sector regarded as spearheading in such practices (KPMG 2015; Albino et al. 2009). Compared to a study by Pascual, Stevels et al. (2003), this result indeed suggests that within this sector, the number of those companies, that are sufficiently mature to communicate quantitative targets, has increased. However, even a larger proportion was expected due to the sector's acknowledged leading role in environmental issues. Nevertheless, it is encouraging that roughly half disclosed such targets. This result seems aligned with the literature reporting that ecodesign implementation

is indeed a journey taking time from policy level to be implemented in practice, and maturing into an ecodesign capability (O'Hare 2010; Stevels 2016).

Figure 10. Bivariate relationships between ecodesign practices; and product development (n=45, arrows denote bivariate significant relationships at p-value 0.05, grey-colored boxes are generic product development (PD) practices and EC means environmental considerations).

In response to RQ1 regarding whether ecodesign practices are associated with each other, Figure 10 above visualizes the detected main bivariate relationships discussed in this section from Publications 1 and 3. This visualizes among others that more established generic product development processes are directly linked with increased considerations for environment in them. Figure 10 also shows that unlike generic product development direct associations between formal management processes and the frequency of earlier product development phases taken, for the ecodesign practices mere formality does not seem to associate directly with the likelihood of more frequent application within these phases in practice. It seems, that other variables might be at the play. Interestingly, the relationship between the role of environmental considerations as a requirement or a mandatory checklist, and the observed benefit from the tool in fulfilling a requirement seem to confirm with the findings in Lindahl (2005).

These results suggest that although the lifecycle thinking as such is widespread, there is room for improvement to include environmental considerations within product development, and to have them mainstreamed as established ecodesign practices. But, the question remains when such a level should be regarded as adequate, and where exactly they should be incorporated for the most impactful outcomes. Perhaps these levels should match at least the levels of generic product development processes. To start with, these results suggest that a fostering context would include among others established general product development process, and properly consider the role of environmental considerations.

5.2 Research question 2: To what extent circular economy considerations are associated with other ecodesign practices?

Nurturing elements for circular economy related activities are assumed to stem overall from more systemized product development processes, and environmental considerations in particular, as discussed alongside responding to the first research question. One such element might include quantitative environmental targets for products, another element might include the knowledge of the product flows throughout their lifecycles. Furthermore, as also noted by other researchers (Blomsma & Brennan 2017; Kirchherr, Reike, et al. 2017), increased shared understanding of terminologies are assumed to nurture such activities. The extent of these types of perspectives were examined in Publications 2 and 3.

Published quantitative environmental targets for products provide an indication of communication and knowledge dimensions within ecodesign capabilities. Such a public commitment would also indicate a more mature ability to internally advance them, see e.g. Hallstedt et al. (2010). The quantitative environmental targets for products that were detected in the sample from the ICT sector, focused on the energy-efficiency, while a smaller number of quantitative targets were detected for circular economy related topics, such as extending the use phase, or enhancing post-use activities. Furthermore, as depicted in Figure 11 shown in next page, Publication 2 extends the study by Pascual, Stevels et al. (2003) by examining the potential relationship with these quantitative environmental targets for products, environmental performance, and selected ecodesign practices related to circular economy. This brings insights into the actual implementation levels related to circular economy within one sector regarded relevant to examine according to Laurenti et al. (2015), Albino et al. (2009) and Bjørn et al. (2017).

The results maintain the understanding that better internal management processes are needed in order to uptake activities related to remanufacturing, an activity necessitating cooperation with various functions both internally and externally (Hatcher et al. 2014). Namely, remanufacturing activities were associated with the quantitative environmental targets for products conforming with the earlier findings in this regard (Montabon et al. 2007). However, it should be mentioned that the prevalence of actual remanufacturing activities was found to be somewhat low similar to one industry-generic study (Sroufe et al. 2002). In contrast, the reporting on repair activities is more common in this ICT sector sample compared with the reporting on remanufacturing, similarly to survey study findings from Malaysia (Khor & Udin 2013). However, repair or refurbish activities are not significantly associated with publishing quantitative environmental targets for products. This result could suggest that such activities do not necessitate equally aligned internal processes compared to those needed for remanufacturing activities.

Environmental performance outcomes were also chosen as proxies for the ecodesign capability dimensions related to knowledge and communication. In Publication 2, this relates to two items. One item is the capability to disclose quantitatively on reclaimed product or packaging flows. This environmental

performance item provides representation of the current knowledge that a company may have accrued from its products' post-use phases. Such knowledge gathering is also recommended in WEEE directive (European Union 2012). To this end, we applied its quantitative information as an indication of an ecodesign capability. It is argued that a company should be cognizant of its product flows throughout their lifecycles before mastering a proper understanding of what to target with its ecodesign practices, or circular economy aspirations (The British Standards Institution 2017). Indeed, the results in Publication 2 indicate that there is a relationship between these topics: The occurrence of quantitative environmental targets for products was significantly associated with the awareness of quantitatively reclaimed product or packaging flows, as shown in Figure 11 below.

The other item used as a proxy for the environmental performance, CDP ranking on performance on climate change strategies, was also associated with the quantitative environmental targets for products. Here no significant relationships were detected with the ranking in the CDP, and circular economy related aspects. This result supports arguments of the complementary nature between issues on circular economy and climate change (Bjørn et al. 2016; Global e-Sustainability Initiative, 2014).

Figure 11. Bivariate relationships with quantitative environmental targets for products and other ecodesign practices; and environmental performance (adapted from Publication 2).

Based on the findings in Publication 2, it seems that companies within the ICT sector are evolving toward a circular economy sphere. An awareness of several terms typically associated with a circular economy are somewhat low in the sustainability reports, apart from the high occurrence of mentioning lifecycle and recycling. This result resonates with another empirical study (Ritzen & Ölundh Sandström 2017) reporting low awareness of circular economy concept as well.

Moreover, the quantitative environmental targets for products influencing the post-use phase were uncommon. Different terms continue to be used to denote ecodesign practices similar to findings by Pascual, Stevels et al. (2003). In addition, contents of terms may remain ambiguous; for instance, if the terms “refurbish” and “remanufacture” are used interchangeably. Hence, investigating

taxonomies to bring more clarity to terminologies would be one meaningful research topic, not only to circular economy as such but also those for example related to remanufacture (Gharfalkar et al. 2016; Blomsma & Brennan 2017; Kirchherr, Reike, et al. 2017; Reike et al. 2018).

One term linked with circular economy discussions is the term “durability”; hence, its awareness could be regarded as a proxy for an interest in the circular economy related activities. In Publication 2, the awareness was at 35 percent at the meso-level based on occurrence of the term from sustainability reports, within the ICT sector. In Publication 3, the survey explored durability perceptions at the micro-level from those individuals working with the product development projects. In the sample based on these observations, the prevalence of durability considerations was inquired related to the extent it had been considered in typical product development projects. The perceived prevalence of considering durability was estimated to be somewhat low in this sample as well: with less than one in three respondents perceiving it to be so. Again, although the different research constructs hinder direct comparisons, this result seems to differ from results based on a quantitative survey by Dietz et al. (2013), and interview study by Dalhammar (2016). In the former study, the sampling criteria may explain the difference, while the latter study did indeed find interest toward durability in general, but not when more detailed topics, such as warranties were inquired about.

Contrary to the expectations, no significant associations were detected with assessed lifecycle and durability aspects in these two separate samples. In the sample from the ICT sector, the association was tested with Fisher’s exact two-sided test to assess the relationship between the occurrence of the terms for lifecycle, and durability. In the survey from Publication 3, two items were analyzed with Spearman correlation. In the survey, the item on lifecycle refers to reporting the perceived extent of lifecycle considerations in the previous past 12 months in product development, while the durability considerations refer to item asking about the extent of being aware of such considerations in typical product development projects. To reiterate, this result comparison is indicative only due to different research constructs.

Based on the results in Publications 1 and 3, we concur with the recommendation by Boks (2006) that if implementation challenges are the main focus of interest, it is meaningful to separately examine product development phases. As an example, selected circular economy considerations were associated with different product development phases. Specifically, in Publication 3, the relationships with durability considerations and other ecodesign practices were examined further. Surprisingly, no associations were detected with examined ecodesign practices, apart from the following ones. Namely, perceiving more frequent inclusion of environmental considerations at task clarification and planning phases correlates positively with perceived durability considerations in typical product development projects. This result should be further investigated to better determine by what means the choices toward aspects of durability become part of the product development processes, or to refute this finding.

Interestingly, in a similar vein, a recent study by Prendeville et al. (2017) categorizes a decision on durability as being strategic, or a hierarchical dilemma rather than an operational or tactical decision. In contrast, perceptions for durability considerations were associated with renewable, and recycled materials in Publication 3. Then, an inverse relationship is detected with reliability and durability considerations similar to the aforementioned study.

To conclude in answering RQ2, it depends which ecodesign practices and circular economy considerations are assessed, as shown above. It seems, for instance, that having environmental quantitative targets is associated with durability, and remanufacturing activities, whereas surprisingly, no association is detected with durability and lifecycle considerations.

5.3 Research question 3: How human factors, such as ecological concern, are related to ecodesign practices?

In Publications 1 and 3, employees' perceptions were examined in order to answer RQ3. This micro-level unit of analysis allows exploring the ways employees' interpretations, for instance, through attitudes and values, might be associated with ecodesign implementation in their product development contexts. In essence, this type of perspective allows an extension of the emerging stream of knowledge into the human factors within the soft-side of ecodesign. It specifically seeks to extend the knowledge in understanding the types of attitudinal factors which seem to hold practical significance for implementing ecodesign.

This is broadly approached with applying the ecodesign capabilities. Other types of approaches have also been examined at micro-level within ecodesign. For instance, Short et al. (2012) applied the risk-aversion theory to approach motivational factors in decision-making. The value of importance attached to environmental considerations has been pronounced earlier by Johansson (2002). These two approaches could be categorized as micro-level factors within the interpretation dimension belonging to the ecodesign capabilities. Lindahl (2005), on the other hand, examined the individual level to better understand what would enhance designers to use environmentally oriented tools and methods, thus, approaching the ecodesign capabilities from a combination of knowledge and interpretation dimensions. Boks (2006) emphasizes the necessity to better understand personal objectives, which would again resonate with the interpretation dimension within the ecodesign capabilities.

To start with, the results indicate that the enjoyment and importance attached to environmental considerations seem to be associated with such phases within product development where more freedom is assumed. In other words, significant associations are found for these two attitudinal factors and with increased frequency to include of environmental consideration at the task clarification and planning phases, as well as at the conceptual phase. However, this was not so with the other ecodesign practices examined, such as requirement related items. Nevertheless, the enjoyment was positively associated with perceived support from top management to include environmental considerations into one's work.

While the norm related to support from top management was further associated with the perceived increased frequency to include environmental considerations into functional requirements, the other attitudinal items were not. In contrast, the perceived support from colleagues to include environmental considerations into one's work, as another proxy for norm, was associated with more frequent inclusion of environmental considerations at later phases of product development. These results seem to indicate the existence of the valuing aspects from the interpretative structures posited by Lenox and Ehrenfeld (1997): while the execution necessitates perceived support from colleagues, in the beginning it is more important to perceive that top management supports inclusion of environmental considerations in product development.

Regarding the finding related to the discussion on proponents and executors. In Publication 1, various functions were assumed to take responsibility with most often cited being product development. This location of responsibility for environmental considerations seems to be associated with the perceived formalized processes to manage product development. Albeit just marginally significant, those respondents representing business or product development considered the processes to include environmental considerations to be more established, than those working with environmental, quality or sustainability functions.

Publication 3 concentrates on the examination of the role of one selected factor at the micro-level in better understanding the extent of ecodesign implementation issues. Interesting insights are revealed by studying respondents' values with a measure first known as the ecological worldview originating from the 1970's, which, to the best of the author's knowledge has not been earlier examined in product development contexts. In Publication 3, the results were expanded with first deriving a measure for ecological concern with seven items from the revised scale for ecological worldview. The extent of ecological concern was found to be high similarly to studies in other types of populations (Hawcroft & Milfont 2010). These seven items in Publication 3 present more of the scale's pro-ecological dimensions in contrast to the scale's items measuring more of the beliefs on dimensions related to human dominance over nature (Lau et al. 2016). It would be insightful to examine ecological concern in other populations representing people working in product development to learn potentially more on the facets of proponents and non-proponents.

Related to the ecodesign practices, not many significant direct relationships were detected between them and the ecological concern. Nonetheless, two intriguing ones were found. First, the ecological concern correlates directly with the perception of formal management processes for environmental considerations in product development. Secondly, the extent of the ecological concern, and the perception of easiness to find environmental information did significantly correlate. Still, the perceived ease of finding environmental information, as a proxy for ecodesign capability to communicate on environmental issues within a company, leaves room for improvement with approximately half the respondents agreeing on this. It is noteworthy that the aspect of easiness to find environmental information - or the lack of it in this research - has been found to slow down

the implementation of ecodesign. Namely, Bey et al. (2013) show that difficulties in finding information on environmental impact was regarded as among the top barriers in implementing environmental strategies. These two results from the survey in Publication 3 seem plausible when it is acknowledged that employees would assumedly notice issues they value within organizations, but on the other hand, they are also realistically aware of their respective organizational constraints for their implementation (Stern et al. 1995).

Turning to knowledge dimension in the ecodesign capabilities, from a more practical level, more associations were found with ecological concern, and few selected circular economy considerations that are also seen as examples of ecodesign practices. Specifically, such associations are detected with ecological concern and items broadly connoted with more resource scarcity aspects (cf. Boks and Stevels, 2007): considering renewables, recycled materials, recovery of plastics and metals, and ease of material separation. Moreover, to our surprise, those respondents with increased ecological concern were more likely aware of considerations for the durability aspects within typical product development projects. These intriguing results suggest to noting these aspects from a fresh dimension. In other words, might it be that some of the arguments for the implementation hurdles in these internal discussions stem from value-laden facets, such as the ecological concern examined in the Publications 1 and 3. For example, in Publication 3, the significant relationship between the perceived considerations for recycled materials and durability was attenuated when the role of ecological concern was controlled for. If so, then this type of examination might provide ways to better comprehend and address arguments for instance, when scoping and framing the circular economy activities within companies (see more in The British Standards Institution 2017).

To conclude in responding to RQ3 about how human factors are associated with ecodesign practices. Enjoyment, and considering it important to work with environmental considerations were associated with more frequent inclusion of environmental considerations in the early product development phases: Namely, the task clarification, and planning, and with conceptual phases. As these are assumed to be those product development phases in which more flexibility, and creativity is called for, it would be important to better understand this relationship between these specific human factors in more details. Then quite interestingly, while the perceived top management support seemed to be associated with functional requirements phase, the support from colleagues seem to be related to those phases in which forthcoming product starts to get its shape in more details. This result confirms with the understanding that environmental considerations should be valued to enhance their application.

Finally, turning to one specific human factor assessed: ecological concern. It seems significantly associated mainly with two perceived meso-level ecodesign practices. These are formal management to include environmental considerations within product development processes, and perceiving it as easy to find information on environmental topics. Hence, no significant relationships are found with the extent of training on environmental considerations, nor with their perceived role within product development or considering them being on

a par with quality, and not with the frequency to include environmental considerations within the product development phases. In contrast, ecological concern is found to associate with the awareness of a few selected circular economy considerations. This seem plausible considering their closer connotations with the NEP items assessed. Figure 12 below summarizes these significant bivariate relationships from Publication 3.

More empirical research is needed to refute these preliminary relationships in other similar samples. Nonetheless, drawing from the interpretative dimension within the ecodesign capabilities framework (see Figure 7 in 2.5), these results suggest that perhaps different types of argument bases, and related skills, are needed to advance ecodesign implementation. Those seeking to advance ecodesign implementation might benefit from understanding these different views from internal stakeholders regarding the role of natural environment and humans, and the ways they might be related to assumptions made towards advancing ecodesign (see also Senge et al. 2008).

Figure 12. Bivariate relationships between ecological concern and ecodesign practices (adapted from Publication 3).

The ecological concern construct coined by Dunlap et al. (2000) might support exploring such relationships with potentially revealing mediating effects among people involved with product development. For example, one interesting way to assess these relationships might be to examine the limits of growth dimensions within the NEP scale, including that of the spaceship earth related item based on Boulding (1966). These results suggest an intriguing insight in advancing the knowledge and practice on issues related to human factors within the soft-side of ecodesign – yet also seemingly linked with the hard-side.

5.4 Limitations

Three areas of concern may limit the interpretations of these results (Malhotra 2004, p. 266-269). Reliability refers to being able to repeat measurements with the similar results, while validity refers to the extent that what is measured relevantly assesses the research problem. The third level of assessment on limitations refers to the extent to which it is possible to generalize from the results to a wider population of interest.

Overall, it is highly unlikely to be able to conduct surveys without some measurement bias. However, to minimize such effects, few remedies were applied that are described in-depth in Publications 1 and 3. For instance, reducing social desirability was sought by allowing an anonymous response format; this may enhance the reliability of the measurement, although using English with potentially non-natives may increase the possibility of misunderstanding some questions. Also, this approach prevented the possibility to triangulate results. Internal reliability with Cronbach alpha was applied for scales. Furthermore, it was seen vital that questions were drawn from extant literature to enhance the nomological validity. In addition, the clarity of questions was tested.

In Publication 2, the following limitations may occur. In terms of the terminology used to conduct content analysis from the sustainability reports related to circular economy – only few selected terms were used in order to increase nomological validity and with the acknowledgement that not all possible terms were analyzed. Another measure was taken to assess the validity (Malhotra 2004, p. 269), the results were tested with environmental performance and selected ecodesign related potential practices for potential relationships: this suggested a plausible framework was applied.

Although content analysis would also provide a way to examine more subjective measures, such as verbs and adjectives, and the way they are linked with target terms for broader context understanding, Publication 2 concentrated on the adoption of key terms to maintain the clarity and relevance of the research objectives, and to minimize potential intended messages by more advanced reporting practices. For the similar reason, triangulation was deemed inappropriate as well. An example of a more context related content analysis could be seen for instance in the research conducted by Bjørn et al. (2017).

Furthermore, it could be reasoned that companies might have unpublished environmental quantitative targets for products. While this is most likely true in many cases, the counterargument is that in such a case, this situation would suggest that they might not be widely applied within companies. This view stems from acknowledging that communicating such target settings would demonstrate more mature practices to advance a company's environmental agenda through their product development practices.

Related to the validity of the NEP scale used, in Publications 1 and 3, the NEP measure with 15 original revised items was used to assess employees' ecological concerns. This construct is subject to an on-going discussion about its dimensions influencing whether it should be assessed as a unidimensional or multidimensional construct, and some even argue for updating some of the items included in the measure. These discussions may advance the understanding of this construct, and its measurement in the future (Hawcroft & Milfont 2010; Dunlap et al. 2000; Amburgey & Thoman 2012). Meanwhile, it is argued that in Publication 3, the nomological validity of NEP was improved by reducing the number of items based on statistical procedure down to seven from the original fifteen (Hair et al. 2010). For instance, this led to the emergence of a similar construct to the original NEP, as five out of seven derived items were already present in that scale.

Finally, these results are not generalizable to other populations covering people working in product development in Finland (Publications 1 and 3), and neither to other populations within the ICT sector (Publication 2). In both samples, the judgmental non-probability sampling was applied at more environmentally oriented contexts, similarly to other studies, such as Handfield et al. (2001), Pascual, Stevels et al. (2003), Bey et al. (2013), and Short et al. (2012). Moreover, both samples exhibit a bias toward organizations that are larger in terms of employees. In Publications 1 and 3, the company background of respondents was biased toward metals and mining, whereas in Publication 2, bias within the ICT sector was related to sample representing companies from electronics and electrical equipment and component manufacturers. Furthermore, the sample sizes may be seen as small. Nevertheless, it is argued that the results in these publications provide new empirical insights into the extent of ecodesign practices within product development contexts complementing the other types of research methods used in the domain.

6. Conclusions

The research objective for this dissertation is to deepen understanding of the context related to enhanced ecodesign implementation within product development. To answer this objective, three research questions were posed for which answers were derived from two types of data using a descriptive research approach. The meso-level analysis is based on data from sustainability reports, whereas the micro-level analysis relies on survey observations from respondents working with product development. The latter is the primary level of analysis applied. This dissertation contributes to the knowledge base by both updating and expanding the understanding of selected issues in more detail. These selected issues consist of ecodesign practices including circular economy considerations, and human factors, such as ecological concern.

Overall, this empirical research confirms that although encouraging signs exist, more is needed to have environmental considerations mainstreamed as implemented ecodesign practices. For example, even in assumingly more environmentally proactive companies, environmental considerations are not frequently included in functional requirements nor is their role yet seen as being always necessary. It is maintained that environmental considerations should proceed beyond the level of 'nice-to-have' before they would succeed in altering product development processes and practices toward minimizing adverse environmental impacts.

Ecodesign implementation issues should also be continued to be highlighted more broadly: While ecodesign is seen as the critical enabler toward circular economy in practice, its implementation hurdles continue to prevail. For example, enhancing ecodesign implementation would also benefit from a shared understanding of the meaning of circular economy considerations in a given context early enough in the product development process. With the current interest in circular economy, this becomes even more critical with such ambitions potentially touching companies' value chains in even more unprecedented ways. It is important to share and to debate the views on the ways assumed changes in relationships may occur in these systems in which company is envisioned to take part in. For instance, seeking to explicate mental models might enhance this.

Indeed, even the concept of a circular economy is just emerging into the lexicon. For instance, an awareness of several terms typically associated with a circular economy appears to be low in the sustainability reports, apart from the

high occurrence of mentions of lifecycle and recycling. Moreover, the quantitative environmental targets for products targeting the post-use phase were uncommon. Hence, these results suggest that such activities remain to be mainstreamed within the ICT sector moving forward within the circular economy sphere. The more mature ecodesign practice in the form of commitment to quantitative environmental targets for products would seemingly advance this, as these results show that such targets were positively associated with a better understanding of their reclaimed product and packaging flows. However, it should be acknowledged that the nature of such activities – such as committing to quantitative targets- occurs slowly. Yet, these results suggest that such progress has occurred within the ICT sector.

On the other hand, these results contribute to the knowledge base by expanding the discussion on aspects on durability which is considered as one of the key issues within circular economy discussions. Results show, interestingly, the ways such considerations were not found to be associated with assessed ecodesign practices, albeit with one exception. The one association found was with the frequency to include environmental considerations in the task clarification and planning phase. Also, intriguingly, durability was not associated with lifecycle items assessed. Indeed, it would be very interesting to deepen understanding on the way durability aspects are determined, including the means by which and in which format they enter the product development process. More research could shed light on the finding based on these results, that durability aspects are shown in some cases be even mediated by ecological concern.

Namely, in overall, these are, to the best of my knowledge, the first published results on the potential influence of an ecological concern, or ecological worldview using the NEP scale, in the context of product development. This would be very interesting to explore further together with a developed understanding of enjoyment, and selected other positive emotions that might be at interplay with each other. Furthermore, NEP scale contains items to circular economy related environmental beliefs, such as that of assessing the respondent's strength in believing that earth is like spaceship with limited resources. Investigating this could shed more light to the interplay with individual's behavior and ecological concern in the organizational context, in which circular economy related ecodesign practices are called for.

Results such as those aforementioned would advance our knowledge by detailing the discussion on the soft-side of ecodesign further. As individuals adopt – or do not adopt - practices in companies including ecodesign practices, it is essential to better understand the means by which human factors may be related to these practices. For instance, those product development phases being assumed to be less formally organized seem to be linked with selected attitudes, such as the frequency of including environmental considerations at conceptual phases with the enjoyment or considering them important. As these examples show, few attitudes and beliefs seem to be associated with ecodesign practices. Principally, it seems that assessed human factors influence at different levels of abstraction also depending on organizational constraints.

One way to advance this could be by examining items from Publications 1 and 3 quantitatively within one company, instead of observations from respondents representing several companies. On such an occasion, it might be possible to gather data from triangulated sources including steering documents for product development projects; other members, that might even originate outside of the company, from the same projects; or meso-level documents, such as sustainability reports. Moreover, it might even be possible to assess several product development projects in order to further determine the role of the human factors, more specifically, ecological concern and positive emotions, within the ecodesign practices. Studying and exploring their potential linkages with ecodesign practices, would advance our knowledge for a better understanding of prevailing attitudes, and the ways in which they might influence the implementation issues in practice.

Indeed, this dissertation offers several stimulating research paths to advance the knowledge base. In addition to the examples mentioned before, conducting a meta-analysis linking other empirically validated results with constructs examined in this research would allow the creation of a theoretical framework for ecodesign implementation in a visually compelling way. In addition, such a compilation might allow a suggestion of ambition levels based on empirical findings of these compiled constructs. And, such a meta-analysis might further reveal new factors and relationships to be empirically tested.

In advancing the knowledge within ecodesign from the research methodology point of view, this research also provides ideas for future research. For example, Publication 2 contributes to this knowledge base by examining the applicability of seldom used research method –content analysis– within the domain in assessing sustainability reports regarding the maturity levels of ecodesign practices in companies. Based on the results published in Publication 2, this research method seems to allow deriving information from sustainability reports. If reporting from several years were examined, it would allow the discovery of interesting insights on journeys that one or several companies have embarked on in progressing ecodesign. This would complement the use of case studies, action research, and surveys currently used within the field.

This research has sought to explicate some recurring themes discussed within the ecodesign domain. Based on these results, it is plausible that companies would benefit from ensuring that all three ecodesign capabilities –knowledge, interpretation and communication - are considered. Yet, further research is needed to better understand the relationships between these ecodesign capabilities, and their role in accelerating ecodesign implementation.

This research came out along the rapidly increasing interest in circular economy, as well as the SDGs: I look forward to continuing further where this path leads next.

Appendix 1. List of SDGs

Goal	Num- ber of targets	Number of indicators
Goal 1. End poverty in all its forms everywhere	7	14
Goal 2. End hunger, achieve food security and im- proved nutrition and promote sustainable agriculture	8	13
Goal 3. Ensure healthy lives and promote well-being for all at all ages	13	27
Goal 4. Ensure inclusive and equitable quality educa- tion and promote lifelong learning opportunities for all	10	11
Goal 5. Achieve gender equality and empower all women and girls	9	14
Goal 6. Ensure availability and sustainable manage- ment of water and sanitation for all	8	11
Goal 7. Ensure access to affordable, reliable, sustaina- ble and modern energy for all	5	6
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	12	17
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	8	12
Goal 10. Reduce inequality within and among countries	10	11
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	10	15
Goal 12. Ensure sustainable consumption and produc- tion patterns	11	13
Goal 13. Take urgent action to combat climate change and its impacts	5	8
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable develop- ment	10	10
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degrada- tion and halt biodiversity loss	12	14
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institu- tions at all levels	12	23
Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Devel- opment	19	25
Total (Note! Number of unique indicators is 232, but nine indi- cators are included within several SDGs, as of 31 Dec 2018)	169	244

(UNSTAT 2018a)

Appendix 2. Questions in the survey

BACKGROUND SECTION

- What is your company's main industry? (36 categories from Eurostat 2008)
- What is your country of location? (197 countries to choose from)
- Is your company a subsidiary of a company from abroad? (Yes, no, I don't know)
- How many employees does your company have? (<10 employees, 10-49 employees, 50-99 employees, 100-249 employees, 250-999 employees, 1000 or more) (Eurostat 2016)
- Typically, what type of customers does your company have? "We have mainly... (...consumer customers/...industrial customers/...institutional customers/...both consumer and industrial/institutional customers/...something else)
- Which of the following alternatives describes your company's main operations? "We mainly... (...manufacture our products/...outsource the manufacturing of our products/...design for others/...manufacture for others/...do something else, please, explain)
- What is your position title? (Open)
- Which of the following alternatives describes your primary functional area? (Electronics/Environmental/Finance/Industrial design/Legal/compliance/Logistics/Manufacturing/Marketing/Materials engineering/Mechanics/Procurement/sourcing/Product development/ Quality/Sustainability/Usability/Something else, please, explain)
How often do you get involved with any activities related to the product/service development projects in your work? (Weekly or more/Monthly/Every few months/Once or twice a year/Never or almost never)

PRODUCT DEVELOPMENT

- Please, list or describe what steps/stages are usually taken in a typical product development project in your company. (Open)(Handfield et al. 2001)
- Regarding how product development is managed, please indicate which of the following statements most closely reflect your company's approach according to your opinion. (Our company operates a formalized and structured product development process (such as a stage and gate or phased and review process)/ Our company has an informal but understood product development process. /Our company does not have a recognizable product development process.) (Options shortened from Short et al. 2012)
- According to your opinion, how frequently does your company undertake each of the following potential stages and practices of product development? (Deutz 2014) (Very often (>81% of the time)/ Often (61 to 80% of the time)/ Commonly (41 to 60% of the time)/ Rarely (21 to 40% of the time)/ Very rarely (<20% of the time)/ Not applicable)
 - Task clarification/planning (Pahl et al. 2007)
 - Functional requirement (Deutz et al. 2013)
 - Conceptual design (ibid.)
 - Embodiment design (ibid.)
 - Detailed design (ibid.)
 - Testing and refinement (Telenko et al. 2008; Ulrich & Eppinger 2012)
 - Considering production (ibid.)
 - Servicing the product/service (ibid.)
 - Consulting customers
 - Consulting suppliers
 - Other
- According to your opinion, does your department conduct product development activities primarily for external or internal clients? (Minimum one from the following list inspired by Hunkeler and Vanakari 2000) (Mostly for external clients/Mostly for internal clients/Both for internal and external clients/Choose not to answer)
- According to your opinion, who are typical external stakeholders that your company engages with during a typical product development project? (Academia, Customer/s, Customer's customers, Recycler/s, Supplier/s for components, materials, parts, etc., Subcontractors, Trade association/s, Other, please, explain, None)
- According to your understanding, how success of a typical product development project is measured in your company? (Open)

ENVIRONMENTAL CONSIDERATIONS IN PRODUCT DEVELOPMENT

- Please, provide example/s of concerns on environment related to products in your industry according to your opinion. (*Open*)
- According to your understanding, to what extent has life-cycle perspective been considered in a typical product development project during the past 12 months? (7-point scale from Not at all - To a large extent)
- According to your opinion, to what extent do you agree that the following are considered in typical product development project/s? (Strongly agree/Mildly agree/Unsure/Mildly disagree/Strongly disagree/Not applicable)
 - Increasing use of recycled materials (*European Union 2009; Ulrich & Eppinger 2012*)
 - Minimizing use of materials (*Boks & Stevels 2007; European Union 2009; Luttrupp & Lagerstedt 2006; Telenko et al. 2008; Ulrich & Eppinger 2012*)
 - Increasing use of renewable materials (*Ulrich & Eppinger 2012*)
 - Maximizing reliability (*Deutz et al. 2013*)
 - Minimizing durability (*Reversed*) (e.g. *Ulrich & Eppinger 2012; Deutz et al. 2013; Luttrupp & Lagerstedt 2006*)
 - Maximizing number of components (*Reversed*) (*Telenko et al. 2008; Mobile Phone Working Group 2010*)
 - Minimizing reusability of components (*Reversed*) (*European Union 2009*)
 - Maximizing stand-by energy consumption (*Reversed*)
 - Ease of disassembly sequence and/or time (e.g. *European Union 2009; Telenko et al. 2008*)
 - Ease of separating materials (e.g. *Mobile Phone Working Group 2010; European Union 2009*)
 - Labelling material/s for recycling (*ibid.*)
 - Ensuring material compatibility for recovery (e.g. *European Union 2009*)
 - Minimizing hazardous substances (e.g. *Boks & Stevels 2007; Luttrupp & Lagerstedt 2006; Ulrich & Eppinger 2012*)
 - Increasing recovery of metals (*Mobile Phone Working Group 2010*)
 - Increasing recovery of plastics (*International Telecommunication Union 2012, p. 32; Mobile Phone Working Group 2010*)
- According to your understanding, what role do environmental considerations have in a typical product development project? "In general, they are mostly regarded as... (Principle/Guideline/Recommendation/ Optional checklist/Mandatory checklist/Requirement/ No formal role/Something else, please, explain)
- According to your understanding, what group or function, if any, is usually given the primary responsibility for monitoring environmental issues during typical product development project/s? (Health and safety/Manufacturing/Marketing/ Product development/ Project Management /Procurement/Quality/ Sustainability/Environmental /Other, please, explain/None/ Not applicable) (*Handfield et al. 2001*)
- Regarding how environmental considerations in product development are managed, please indicate which of the following statements most closely reflect your company's approach according to your opinion. (Our company does not have a recognizable process to include environmental considerations in product development process. /Our company has an informal but understood process to include environmental considerations in product development process. /Our company operates a formalized and structured process to include environmental considerations in product development process. /I don't know.) (*Inspired by Short et al. 2012*)
- According to your opinion, how frequently does your company include any environmental considerations in each of the following potential stages and practices of product development? (Very often (>81% of the time)/ Often (61 to 80% of the time)/ Commonly (41 to 60% of the time)/ Rarely (21 to 40% of the time)/ Very rarely (<20% of the time)/ Not applicable)
 - Task clarification/planning,
 - Functional requirement,
 - Conceptual design,
 - Embodiment design,
 - Detailed design,
 - Testing and refinement,
 - Considering production,
 - Servicing the product/service,
 - Consulting customers,
 - Consulting suppliers,
 - Other

- According to your opinion, what tools, methods and/or other aids are used to facilitate the consideration of environmental topics in a typical product development project? (*Open*)(*Handfield et al. 2001*)
- According to your opinion, have you received following potential benefits while using methods, tools or/and aids related to environmental topics in your work during the past 12 months? Please, choose all that apply (*Minimum one*)
 - It helped me to fulfill specified requirements on prospective product. (*Lindahl 2005*)
 - It reduced my total calendar time (from start to end) to solve a task. (*ibid.*)
 - It transferred the results directly to other product development tool.
 - It facilitated me to share information. (*Inspired by ibid.*)
 - I did not use any tool, method or aid to consider environmental topics in my work during the past 12 months.
 - Something else, please, explain
- According to your opinion, to what extent do you agree with the following statements? (Strongly agree/Agree/Mildly agree/Unsure/Mildly disagree/Disagree/Strongly disagree)
 - It is not easy to include environmental considerations in my work. (*Reversed*)
 - Our team should include more environmental considerations into a typical product development project.
 - Environmental criteria have same importance than quality criteria in a typical product development project. (*Inspired by Handfield et al.2001, Boks 2006*)
- According to your opinion, what factors would enable and/or restrict you to consider environmental topics in your work in the next 12 months? (*Open*)

COMPANY GENERIC AND YOUR WORK

- According to your understanding, to what extent do you agree that "Our company has..." (Strongly agree/Mildly agree/Unsure/Mildly disagree/Strongly disagree)
 - Quality policy
 - Quality system certified according to ISO9000 or similar
 - Code of conduct/ethics
 - Code of conduct/ethics for suppliers
 - Sustainability policy/guidelines
 - Environmental policy/guidelines
 - Environmental management system
 - Environmental management system certified according to EMAS/ISO14000 or similar
 - Environmental objective/s
 - Environmental requirements for suppliers
 - Other, please, explain
- According to your understanding, which of the following potential sustainability topics have been in focus in your work during the past 12 months? Please, choose 1-5 alternatives that apply:
 - Quality; Climate change; Energy-efficiency; Recycling; Extension of life-time; Hazardous materials restrictions; Waste and pollution reduction; Weight of product; Weight of packaging; Ethical impacts; Health and safety impacts; Human rights; Working conditions; Responsible supply chain; Something else, please, explain; None of the above
- According to your opinion, to what extent do you agree on the following statements? (Strongly agree/Agree/Mildly agree/Unsure/Mildly disagree/Disagree/Strongly disagree)
 - Our top management encourages to include environmental considerations in our work during the next 12 months.
 - Most colleagues that are important to me, think that I should not implement environmental considerations in my work during the next 12 months. (*Reversed*)
 - I have received enough of environmental training/s in our company.
 - It is easy to find information related to environment in our company.
 - I have included environmental considerations in my work during the past 12 months.
 - I enjoy including environmental consideration/s in my work.
 - It is not important to include environmental considerations in my work during the next 12 months. (*Reversed*)
 - If I wanted, I could in most instances include environmental considerations into my work during the next 12 months.
 - I intend to include environmental considerations into my work during the next 12 months.
 - I don't feel moral obligation to include environmental considerations in my work during the next 12 months. (*Reversed*)

- I will make an effort to include environmental considerations in my work during the next 12 months.
 - I am used to include environmental considerations in my work.
- According to your understanding, what are main reasons to consider sustainability topics in your company? (Please, choose 1-5 alternatives that apply)
 - Benchmarking product groups – internal
 - Benchmarking product groups – external
 - Commitment to voluntary standard/s
 - Company image
 - Competitor/s
 - Cost savings
 - Customer suggestion/s
 - Customer request/s
 - Internal - general interest
 - Internal - our team's /own interest
 - Internal environmental objective/s
 - Legislation or regulation – current
 - Legislation or regulation – forthcoming
 - Part of our LCA (Life Cycle Assessment) practices
 - Pressure from community groups
 - Pressure from non-governmental organization/s (NGO's)
 - Something else, please, explain
 - None of the above
- According to your understanding, how do you measure progress in sustainability-based topics in your company? (*Open*)
- According to your opinion, what types of sustainability-based incentives are provided in your company? (Minimum one to be chosen)
 - I have individual non-monetary incentives.
 - I have individual monetary incentives.
 - Our team has non-monetary incentives.
 - Our team has monetary incentives.
 - Our projects contain non-monetary incentives.
 - Our projects contain monetary incentives.
 - We have non-monetary incentives at company level.
 - We have monetary incentives at company level.
 - Our company does not have non-monetary incentives.
 - Our company does not have monetary incentives.
 - Something else, please, explain
 - I don't know
 - Choose not to answer

BACKGROUND – RESPONDENT

- (*Dunlap et al. 2000*) "Listed below are statements about the relationships between humans and environment. For each one, please, indicate whether you 1- STRONGLY AGREE 2 - MILDLY AGREE, are 3 - UNSURE, 4 - MILDLY DISAGREE, 5 - STRONGLY DISAGREE with it.
 - We are approaching the limit of the number of people the earth can support.
 - Humans have the right to modify the natural environment to suit their needs.
 - When humans interfere with nature it often produces disastrous consequences
 - Human ingenuity will insure that we do NOT make the earth unlivable.
 - Humans are severely abusing the environment.
 - The earth has plenty of natural resources if we just learn how to develop them.
 - Plants and animals have as much right as humans to exist.
 - The balance of nature is strong enough to cope with impacts of modern industrial nations.
 - Despite our special abilities humans are still subject to the laws of nature.
 - The so-called "ecological crisis" facing humankind has been greatly exaggerated.
 - The earth is like a spaceship with very limited room and resources.
 - Humans were meant to rule over the rest of nature.
 - The balance of nature is very delicate and easily upset.
 - Humans will eventually learn enough about how nature works to be able to control it.
 - If things continue on their present course we will soon experience a major ecological catastrophe."
- Your age group: (<25, 25-34, 35-44, 45-54, 55-64, 65+)

- What is the highest level of educational degree that you have completed? (Primary education/High school diploma or equivalent/Bachelor's degree/Master's degree/Doctoral degree/Other, please, explain)
- Please, write here any comments and suggestions related to this survey. Thank you for your time. (*Open*)

(Please note that applicable parts of survey were published also in Publication 1 and 3.)

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