Defining the challenges for ecodesign implementation in companies: development and consolidation of a framework

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Abstract
This study addresses the problem of the slow take-up of ecodesign in industry by identifying and categorising the implementation challenges faced by practitioners. Case studies from nine manufacturing companies from five different countries are reported based on interviews with key ecodesign personnel. A literature-derived framework is used to analyse each case, allowing for robust cross-case analysis. Challenges are identified in five areas: strategy, tools, collaboration, management and knowledge. The *management* category of challenges is the most frequently mentioned by the companies sampled. The *tools* category is not as prominent as might have been expected given the on-going focus on tool development within this field. The main contributions of the study are the updating of the main challenges for ecodesign implementation faced by industry, and the development of a rich framework of challenges, including new challenges not previously mentioned in the literature. It is suggested that the framework can be used (and evolved) by other ecodesign researchers when developing surveys or questions for in-depth case study interviews as this will facilitate more robust comparisons between studies and support the development of a more consolidated body of knowledge in this field.

Keywords
Ecodesign; Design for Environment; Implementation; Challenge; Framework.

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1. Introduction

'Ecodesign' is defined by ISO 14006:2011 as the integration of environmental aspects into product design and development with the aim of reducing adverse environmental impacts throughout a product's life cycle (ISO, 2011). The extent to which ecodesign practices are implemented in industry has been concerning researchers for many years (Tukker et al., 2001). Recent studies show that companies are still struggling to implement ecodesign (Bey et al., 2013; Lee-Mortimer and Short, 2009). The implementation of ecodesign practices in industry is not advancing at the rate necessary to achieve a more sustainable society. This slow progress is somewhat puzzling as, from an academic perspective, the body of knowledge in this domain has steadily developed and evolved over the last 30 years to a state where we now have a reasonably mature and comprehensive set of good-practice processes, management principles and supporting tools (Boks and McAloone, 2009).

The ecodesign research community have begun investigating and ameliorating the slow rate of adoption of ecodesign in industry. A common approach has been to identify: on one hand the drivers, best-practices and success factors for ecodesign implementation; and on the other hand, the challenges and barriers (Bey et al., 2013; Johansson, 2006; O'Hare, 2010). The characterisation of drivers, best practices and success factors seems to be well-advanced (Pigosso et al., 2013). In contrast, the characterisation of barriers and challenges is less complete.

Whilst there is a significant amount of literature that aims to help companies get started on ecodesign (Crul and Diehl, 2005; McAloone and Bey, 2009), or that report on ecodesign pilot studies (Domingo et al., 2015; Knight and Jenkins, 2009; Luttropp and Lagerstedt, 2006), there is very little literature reporting on companies that have significant experience of implementing ecodesign. Exceptions include the cases reported by Prendeville et al. (2011) and Boks & Stevels (2003). This may be because there are very few companies that have significant experience in implementing ecodesign. Alternatively, it may be that such companies are reluctant to share details of their ecodesign implementation activities with the research community as this might affect any competitive advantage they have in this area.

So whilst there is now a body of knowledge concerning ecodesign implementation, there are at least two key areas that have not been sufficiently studied. First, the identification of the challenges faced by companies that are implementing ecodesign. Secondly, the experiences of companies which have a significant track record in implementing ecodesign. This study attempts to address both of these knowledge gaps by focussing on the challenges of implementing ecodesign faced by companies with significant experience of ecodesign.

A final consideration in shaping the focus of this study was the desire to concentrate on the challenges that industry practitioners have influence over, and can feasibly take action on. For example, it may be that poor integration within higher education policy and a lack of legislation to encourage ecodesign are significant factors in explaining the slow progress of ecodesign implementation in industry. However, industry practitioners have very little influence on these issues and so they were not considered in this study. Therefore the scope focused on the barriers to ecodesign implementation that practitioners in experienced companies have encountered, and have some influence over. This led to the definition of the first of two research questions, as follows:

"What are the challenges faced by manufacturing companies during ecodesign implementation?"

The second research question related to the observation that domains such as ecodesign and eco-innovation are inherently inter-disciplinary and are therefore at greater risk of becoming fragmented (O'Hare and McAloone, 2014). To address this potential for fragmentation, the second research question was defined as follows:

"Can the challenges for ecodesign implementation be structured in a way that will help to consolidate the research in the field?"

This paper draws together the experiences from three research centres across Europe that have significant experience of working with industry on ecodesign. The aim of the paper is to highlight the most common challenges faced by industry in the implementation of ecodesign today. The paper presents findings from the ecodesign experiences in nine manufacturing companies from five different countries. The case-studies have all been conducted using the same framework of ecodesign implementation challenges to enable robust comparison across the diverse cases. The construction of the framework of ecodesign implementation challenges for use in the study is presented as a research output in its own right.

2. Methods applied in the study of the drivers and barriers for ecodesign implementation

To begin answering the second research question on the structuring of ecodesign challenges, a review of the academic literature was completed. The two objectives of the review were to build a better understanding of: how previous researchers have studied ecodesign implementation challenges (i.e. which research methods used); and how had they used the results from previous research to guide the design and analysis of their own studies. From this review, the two most common methods identified were surveys and individual (or small sample) in-depth case studies. The following two sub-sections describe some examples of studies that employ these methods.

2.1 Surveys on ecodesign implementation in companies

Table 1 presents key details of some representative examples of survey-based studies on ecodesign implementation in industry. The examples selected demonstrate some of the varied aspects of ecodesign implementation that have been investigated using surveys. For instance, Bey et al (2013) and Kara et al (2014) had a particular focus on the use of ecodesign tools. Lee-Mortimer and Short (2009) and Deutz et al (2013) were interested in the integration of ecodesign into a company's New Product Development process. Santolaria et al (2011) investigated the link between the innovation competency of a company and their ecodesign implementation status. Finally, Short et al (2012) and Kara et al (2014), through the use of international survey samples, have analysed inter-country variations in ecodesign implementation activities.

When reviewing the studies particular attention was given to understanding the extent to which results from previous studies had been used to generate the research hypotheses and/or survey questions – the results are shown in the second column of Table 1.

All of the articles introduce some of the relevant literature but only two out of the ten studies (Akman et al., 2011; Cai and Zhou, 2014) reported either: clear, traceable links between previous findings and the research hypotheses/survey questions; or used a conceptual model derived from literature. Furthermore, it was found that the reporting of survey questions was highly variable in terms of completeness. In three

studies from our sample the survey questions are not reported at all. In another three studies the survey questions are presented in a condensed form or have to be deduced by the reader based on the responses presented in the results section. These short-comings in structure and detail, make it difficult for researchers performing subsequent survey studies to replicate, strengthen and build upon those earlier findings.

Study authors and aim	**Origin of research hypotheses and survey questions**	**Sample characteristics**	**Method**
Cai & Zhou (2014). *Aim:* Investigate drivers for eco-innovation in China	Conceptual model of eco-innovation drivers derived from literature. Interview with 50 CEOs to validate survey. Full questionnaire presented in appendix.	*Size:* n=1266 *Response rate:* 33% *Sectors:* Building materials, chemical engineering, electric power, energy, machinery, steel, transportation, and textiles. *Geography:* China *Participant profile:* CEO or manager	Face-to-face interviews and email.
Bey et al. (2013). *Aim:* To understand why industry adoption of ecodesign approaches and tools are not advancing more rapidly.	No details of origins of hypotheses of questions. Questions presented in shortened form.	*Size:* n=80 *Response rate*: 16% *Sectors:* Various *Geography:* Mainly Danish, EU and US companies. *Participant profile:* Not reported.	Multi-choice internet survey.
Short et al (2012). *Aim:* Compare uptake of ecodesign in UK and Sweden.	No details of origins of hypotheses of questions. Questions presented in results section and linked to hypotheses.	*Size:* n=72 Sweden, n=54 UK *Response rate*: 18% Sweden, 0.2% UK *Sectors:* Various *Geography:* UK & Sweden *Participant profile:* Not reported.	Web survey.
Deutz et al. (2013). *Aim:* Investigate integration of ecodesign into the design process and current practice.	No details of origins of hypotheses of questions. Questions presented to some extent through results.	*Size:* n=93 *Response rate*: 4% *Sectors:* Various *Geography:* UK *Participant profile:* Not reported.	Postal survey. Follow-up interviews with 11 companies.
Santolaria et al. (2011). *Aim:* To empirically investigate the cross-sectional connection between innovation driven companies and ecodesign.	No details of origins of hypotheses of questions. Survey questions refined and validated by 30 industry professionals. Questions shown in appendix.	*Size:* n=846 *Response rate*: *8%* *Sectors:*Various *Geography:* Spain *Participant profile:* Mostly managers (46%	Email with link to web survey.
Kara et al. (2014). *Aim:* Compare drivers for ecodesign and types of tools used across different countries.	12 hypotheses tested – linked to 4 research questions but origins not explicitly identified. Condensed form of questions shown.	*Size:* n=330 *Response rate*: not reported *Sectors:* Various *Geography:* 13 countries (Asia, Australia, Europe, N America) *Participant profile:* Middle and top management	Email and postal survey.

Cordoba & Veshagh (2013). *Aim:* Investigate drivers and barriers for ecodesign in industry	No details of origins of hypotheses of questions. Questions not given.	*Size:* n=258 *Response rate*: not reported *Sectors:* machinery, equipment and instruments, Food and drink and various others. *Geography:* UK *Participant profile:* Not reported.	Survey – no detail of format.
Veshagh et al. (2012). *Aim:* To compare literature with industry's perception of the drivers, barriers, benefits and risks of sustainable design and manufacturing.	No details of origins of hypotheses of questions. Survey questions not reported.	*Size:* n=158 *Response rate*: not reported *Sectors:* machinery, equipment and instruments, 10% metal materials, rest from various. *Geography:* UK *Participant profile:* Not reported.	Email survey and face-to-face interviews.
Akman et al. (2011). Investigate status of ecodesign implementation in Turkish automotive supply chain.	All questions derived from findings of previous research with references provided. Questions shown.	*Size:* n=61 *Response rate*: not reported *Sectors:* Automotive supply chain. *Geography:* Turkey. *Participant profile:* Education, gender and experience of participants reported.	Face-to-face interviews.
Chaouy (2007) *Aim:* Evaluate the evolution of needs from companies toward ecodesign (benefits and drivers from implementation)	No details of origins of hypotheses of questions. Questions not given.	*Size:* n=44 *Response rate:* not reported *Geography:* France *Participant profile:* 9 trade unions' representatives, 25 individuals from companies and 10 representative for collective actions at the regional level.	Phone calls

Table 1. Studies of ecodesign implementation employing a survey method.

To enable researchers to strengthen and build upon previous findings in the field, two complementary actions are proposed. First, it is suggested that when reporting on a survey, researchers should make clear and explicit links between existing literature, the research hypotheses and the survey questions that were used. The second action proposed is the development of a common framework for the categorisation of ecodesign implementation challenges. The second research question of this study aims to address this second proposed action. It is hoped that this type of framework can serve as the foundation for studies of ecodesign implementation and thereby help to reduce the risk of fragmentation of this research domain.

2.2 Case studies on ecodesign implementation in companies

A number of studies have used in-depth case studies to investigate ecodesign implementation in industry. These have either been based on the study of one company or on a small sample - typically no more than three companies. These studies can be further separated in two categories: studies aimed at *building up knowledge* on what is happening inside the companies concerning the topic of ecodesign; and studies aimed at *testing specific interventions* in the companies' processes - mainly through tool integration. Johansson (2006) is an example of the first, knowledge building category. Johansson's contribution reflects on two product development projects in the electronics sector that included environmental

requirements. He used open-ended semi-structured interviews with more than 10 people on each project, internal written documents and participation in meetings to structure a two-dimensional model for ecodesign processes. However, his framework for the semi-structured interviews is not detailed.

Domingo et al (2015) also falls in the first category. They used two different techniques for their case studies of the business context for ecodesign implementation. The first one, in the automotive sector, was a retrospective analysis, based on action research within the company. The second one, in the domestic appliances sector, was based on in-depth interviews with design and management team members and the analysis of internal documents. The framework for interviews is not detailed.

In the second, intervention testing category, most of the contributions reflect on feedback from ecodesign tool implementation activities such as:

- Knight and Jenkins (2009) who used focus groups to identify the best tools to support ecodesign implementation in a medium size company manufacturing lighting equipment.
- Prendeville et al. (2011) who used semi-structured interviews (with designers and suppliers) and ethnographic observations of an SME - a furniture design company - to study assessment tools.
- Luttrop and Lagerstedt (2006) reflected on the adaptation of their "Golden Rules" into the product development process of a large company. The research methods used for the "follow-up" assessment is not clearly defined but it gathered feedback from "many people".
- Boks and Stevels (2007) summarised the results from a long collaboration between their university and a large company from the electronics sector.

All four examples try to assess the effectiveness of an intervention. However, it is difficult to make such assessments without having further data available concerning the wider context of the intervention in terms of the drivers and barriers of ecodesign implementation that were present at the time of the intervention. By capturing and reporting a snapshot of the context, both before and after the intervention, other researchers and practitioners would be better able to evaluate for themselves the effectiveness of the intervention reported and its suitability for use in their own applications. Furthermore, if this type of contextual information about the drivers and barriers for ecodesign implementation were captured using a common framework it would enable more effective comparisons to be made from one company to another and from one study to another.

As in section 2.1, this section shows: that there is a need for a common framework of ecodesign implementation challenges. Applied to in-depth case studies, this type of framework would support:

- Researchers in the evaluation of the effectiveness of ecodesign interventions;
- Practitioners when deciding if the interventions proposed by the research community are appropriate for their own context;
- Better comparisons between case studies.

The first iteration of such a framework for the challenges of ecodesign implementation is presented in Section 4.

3. Methodology

The research presented in this paper followed a hypothetic-deductive approach (Gill and Johnson, 2002) which aimed to develop, test and refine a framework of challenges that companies face when implementing ecodesign. The hypothetic-deductive approach entails the development of a conceptual and theoretical structure prior to its testing through empirical observation. The empirical observation aims at falsifying the proposed theory and finding new evidences to improve it (Lancaster, 2005). In this context, the research was carried out in three main phases: theory development, theory testing and theory improvement. The theory was developed and tested by focusing on the challenges faced in manufacturing companies during ecodesign implementation, thereby contributing to our first research question. The results from the three phases of the research together answer the second research question.

3.1 Phase 1: Theory development - Development of a framework of implementation challenges for ecodesign

A framework of the main challenges faced by manufacturing companies for ecodesign implementation was developed based on a comprehensive literature review, which comprised journal and conference papers dealing with the identification of challenges for ecodesign implementation over the last 20 years. In total, 46 papers were gathered and analysed. This work was done collaboratively benefitting from the range of authors involved in this paper.

The papers were analysed to identify the challenges. In total, 29 challenges were identified and grouped into five 'categories': strategy, tools, collaboration, management and knowledge. Subsequently, the categories were de-composed into 'themes', and 'sub-headings' to allow analysis at a more granular level of detail. A summary of the literature used to create the framework and the initial framework itself are presented as the first research results in sections 4.1 and 4.2.

3.2 Phase 2: Theory testing – Multiple case studies

Multiple case studies were completed to test the framework of ecodesign implementation challenges that had been developed. Multiple case studies were selected as a research methodology, as they enable an enhancement of the degree of confidence that the theory is correct for a specific domain (Dul and Hak, 2008). A failure to find rejections of the hypothesis or proposed concepts in many different attempts (replications) increases the confidence that the proposition might be generalizable to the theoretical domain (Dul and Hak, 2008).

The steps carried out for the development of the multiple case studies were:

Step 1: Development of a case study protocol and questionnaire

An interview protocol was developed to aid the data gathering within the case study companies. The aim of the protocol was to identify the main challenges faced by manufacturing companies for ecodesign implementation. The interview questions were divided into three main blocks:

- Block 1 - Contextual questions: open questions to characterize the company, the respondent(s), and to identify main drivers, previous and ongoing projects related to ecodesign implementation;
- Block 2 - Checklist with the ecodesign implementation challenges: semi-structured questionnaire based on the framework of challenges (from phase 1);

- Block 3 - Ranking of challenges' importance: assessment by the interviewee of the most important categories in the proposed framework from his/her viewpoint.

Step 2: Selection of the case study companies

The main criterion for the selection of the case study companies was that they needed to have significant experience[3] in ecodesign implementation (i.e. at least one employee with formal responsibilities for supporting ecodesign, having been in place for at least two years). This criterion aimed to enable the identification of challenges from companies that have tried to implement multiple ecodesign initiatives or multiple stages of a longer-term ecodesign initiative, in order to be able to express the main challenges faced in implementing ecodesign.

In total, nine manufacturing companies were selected for study from a longer list of companies that the research partners had had previous contact with regarding ecodesign practice. The selection of the companies was done to ensure varied sectors, company sizes and geographical locations Table 2 provides a characterization of the companies and the employee(s) involved in the interviews. The selection of diverse companies enables the researchers to test the proposed framework in varied settings and contexts. Challenges related to the very early stages of ecodesign implementation in companies are not captured in this research.

[3] The experience of a company is measured by the number of years in which ecodesign has been applied in the organization, which might involve one or more practitioners.

	Company characteristics				*Interviewees' characteristics*		
Company	*HQ location*	*Sector [1][4]*	*No. of employees & Business type*	*Company's Ecodesign experience*	*Time in company*	*Job title*	*Ecodesign experience [5]*
Company 1 (C1)	Denmark	C32 - Other manufacturing	9,000 B2B and B2C	12 years	8 years	Senior EHS specialist	12 years
Company 2 (C2)	Brazil	C30 - Manufacture of other transport equipment	19,000 B2B and B2C	4 years	20 years	Ecodesign Manager	5 years
Company 3 (C3)	France	C26 - Manufacture of computer, electronic and optical products	900 B2B and B2C	2 years	18 months	Quality and CSR	2 years
Company 4 (C4	Denmark	C27 - Manufacture of electrical equipment	18,000 B2B and B2C	20 years	4 years	Head of ecodesign	2,5 years
Company 5 (C5)	Germany	C32 - Other manufacturing	2,000 B2C	30 years	29 years	President	29 years
Company 6 (C6)	UK	C29 - Manufacture of motor vehicles, trailers and semi-trailers	25,000 B2C	10 years	8 years[6] 3 years[6]	Part leader Part leader	8 years 13 years
Company 7 (C7)	Brazil	C20 - Manufacture of chemicals and chemical products	7,000 B2C	3 years	8 years	Ecodesign scientific manager	10 years
Company 8 (C8)	France	C29 - Manufacture of motor vehicles, trailers and semi-trailers	117,600 B2B and B2C	2 years	14 years	Ecodesigner	20 years
Company 9 (C9)	France	C13 - Manufacture of textiles	6 B2B	6 years	15 years	Director	5 years

Table 2. Overview of the key characteristics of the case study companies and of the interviewees

More detailed descriptions of the case study companies are provided in the Appendix.

Step 3: Performance of multiple case studies

The main research method for data collection in the case companies were semi-structured interviews, following the interview protocol and questionnaire developed in step 1. The interviews with the selected companies had an average duration of 90 minutes and involved one or two people directly engaged in ecodesign implementation. Face-to-face interviews were performed where feasible and telephone

[4] Classification based on the International Standard Industrial Classification of All Economic Activities, Rev.4 (http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27).

[5] The experience of the interviewees is measured based on the number of years they have been working with ecodesign throughout their carriers, including previous positions in other companies. Note that the time of experience in ecodesign of the interviewee and the company might differ as the employee might have previous experience on ecodesign before joining the company.

[6] A joint interview with two people was conducted at Company 6.

interviews were used in four cases. The interviews were generally conducted by one interviewer, with either an audio recording or a second researcher taking notes as a means of ensuring that an accurate record of the interview was generated.

Step 4: Consolidations and analysis of the results
A variety of complementary techniques were employed to analyse the results from each of the questionnaire blocks. Qualitative analysis was used to contextualize each of the specific results of block 1 (contextual questions), this provided the data for Table 2 and the case descriptions included in the appendix.

The analysis of block 2 (checklist of challenges) involved a quantification of the most recurrent challenges across different companies. Three independent researchers classified the challenges quoted in each one of the nine companies using the categories, themes and sub-headings from the framework. Several rounds of analysis were performed until the researchers reached a consensus on the classification for all of challenges in the data set. Based on the final classification, a quantitative analysis was performed in order to identify the most frequently mentioned challenges. This metric (i.e. the number of companies mentioning a challenge) is labelled 'recurrence' in tables 3 and 4 and is used to create the bar charts in figures 1 to 3.

Block 3 (the interviewees' ranking of the challenges) was analysed by comparing the interviewee ranking of the challenges with the quantitative analysis from block 2. Given that statistical methods were not appropriate for the sample size, this comparison provided triangulation to strengthen the conclusions regarding the framework of the challenges for ecodesign implementation.

3.3 Phase 3: Theory improvement – Enhancement of the ecodesign challenges framework

Based on the results of the multiple case studies, the proposed framework for ecodesign challenges was further improved with the addition of new challenges that were mentioned in the case studies but were not identified in the literature review performed in Phase 1. Furthermore, the robustness of the proposed framework was enhanced in terms of wording and vocabulary. These enhancements are presented in Section 4.3.2.

4. Results

The results section is organised into four sub-sections which together provide answers to both research questions. In sub-section 4.1 the summary of the literature used to create the framework is presented. Sub-section 4.2 shows the initial framework itself. Section 4.3 presents the cross-case analysis of the data at sub-heading, theme and category levels and shows how the framework was enhanced with new sub-headings from the data set. Sub-section 4.4 provides a comparison between the challenges that the interviewees subjectively considered to be most significant with the results from sub-section 4.3.

4.1 Summary of the literature used for the initial framework

The literature was grouped into five categories, which are presented below. These went on to be the 'categories' in the framework.

STRATEGY

The implementation of ecodesign requires support from senior management (Boks, 2006; Pigosso et al., 2014) and a business strategy that places some emphasis on improving the environmental performance of the company and that evolves with time (Hallstedt et al., 2010). Developing and implementing such a strategy is particularly difficult for Small to Medium sized Enterprises (SMEs) as they often have fewer resources and focus on short terms constraints and survival rather than long-term objectives (Le Pochat et al., 2007; Reyes and Millet, 2013; Zhang et al., 2013). More generally it has been reported that companies often do not know how to incorporate ecodesign and environmental aspects into the strategic decision-making process (Baumann et al., 2002; Bonn and Fisher, 2011; Pascual and Stevels, 2004).

All challenges in the *strategy* category therefore concern: business strategy, long-term strategic objectives or strategic decision-making tools.

TOOLS

There has been a significant focus within the academic literature on the development of new tools to support ecodesign. However, this has created two problems. First, the relative abundance of ecodesign tools makes it more difficult for practitioners to select the tools that are most relevant to their needs (Boks and Stevels, 2007). Secondly, it seems that the focus on new tools in industry and academia has been at the detriment of understanding more about how the existing range of tools can be further developed and more effectively adopted into industrial practice (Baumann et al., 2002; Bovea and Pérez-Belis, 2012; Collado-Ruiz and Ostad-Ahmad-Ghorabi, 2010).

To address these issues, there have been some attempts to understand how tools can be selected and implemented more effectively. For example, Reyes & Millet (2013) found that the collaborative development of a tool, including the intended users, increases the chances that the tool will be adopted by those users. It has also been found that the information systems used within companies often do not fully support the exchange of the types of data that are important for ecodesign e.g. carbon footprint of materials and components or water usage in manufacturing processes (Reyes and Millet, 2013; Rio et al., 2013; Zhang et al., 2013).

There are also challenges with the implementation of specific tools, such as Life Cycle Assessment (LCA) tools. For example, applying LCA tools requires a lot of resources (data, time, experts…) (Michelin et al., 2014; Millet et al., 2007) and it can be difficult to utilise the results of an LCA tool to actually inform decisions during the design process (Kozemjakin da Silva et al., 2013).

All challenges in the *tools* category therefore concern: the development, selection, implementation, or adoption of tools; and the effects of tools on ecodesign.

COLLABORATION

Ecodesign is inherently a multi-disciplinary activity as it requires input from stakeholders across all phases of the product lifecycle and spans both the environmental and engineering design domains (Boks, 2006; Wolf, 2013). The challenges that arise from this include problems in communication (Lu et al., 2007) and resistance to changing the way stakeholders work together. These challenges become even more difficult to overcome when collaboration with external stakeholders is required. For example,

implementing ecodesign may require a change in the usual client/supplier relationships where the client has to become more pro-active to discuss environmental hotspots with suppliers and work together to identify solutions (McAloone et al., 2010). Also, given that bought-in components often represent a significant proportion of a product's total life cycle environmental impacts, it is often important to engage suppliers in ecodesign activities. However, companies often fail to identify who the key suppliers are that they need to engage with (Domingo et al., 2015) or find it difficult to obtain the information they require from those suppliers as they are not used to providing environmental information about their products (Mombeshora & Dekoninck, 2013).

All challenges in the *collaboration* category therefore concern: all issues relating to internal and external stakeholders and their communication.

MANAGEMENT

Another major focus has been on the management of ecodesign activities, and in particular, how ecodesign can be integrated into the New Product Development (NPD) process. Many authors have found that companies struggle to achieve this integration (Bakshi and Fiksel, 2003; Dangelico and Pujari, 2010; Johansson, 2006; Le Pochat et al., 2007; Luttropp and Lagerstedt, 2006). In particular, companies find it difficult to integrate environmental considerations into the early stages of the NPD process because their existing NPD process is less formal in these early stages (Mougenot et al., 2008). This leads to the problem that management processes may only begin to encourage consideration of environmental factors later in the NPD process, by which point the opportunity to radically innovate is already passed (Tyl, 2011).

Standards such as ISO 14006:2011 (ISO, 2011) have been developed in recent years to provide guidance to companies on how to integrate ecodesign into existing management systems. However, several authors have concluded that companies lack the systematic approach or roadmap that is required to achieve environmental goals and maintain a 'continuous improvement' approach within the development of their products and processes (Boks and Stevels, 2007; Marimon et al., 2011).

A further management challenge is that implementing ecodesign creates new requirements to be met by the design team but those environmental requirements are just one part of the many types of requirement that a successful NPD project must deal with (Luttropp and Lagerstedt, 2006). This requires the design team to make trade-offs between the various requirements, which can be difficult. This challenge is made more difficult by the fact that companies often do not provide additional time and resource to the design team to address the new environmental requirements they have been set (Bey et al., 2013).

All challenges in the *management* category therefore concern: the integration and resourcing of ecodesign activities in NPD and management systems.

KNOWLEDGE

Introducing ecodesign requires a large amount of knowledge development, both within the design team and the supporting business functions (marketing, production, purchasing) (Domingo et al., 2015). Currently, many companies lack the necessary environmental knowledge to support ecodesign activities (Ilgin and Gupta, 2010). According to Millet et al. (2007) there are three main ways that a design team

can acquire the environmental knowledge and expertise that they require: integration of a new expert in the design team; ask an existing team member to develop the specialist expertise; or support the integration by introducing new tools and methods across a broader range of the team. Many authors seem to favour the introduction of an ecodesign expert or champion, but even then, there is a challenge in deciding how and where to involve such a person (Kozemjakin da Silva et al., 2013).

As well as acquiring new knowledge and expertise, companies implementing ecodesign must also acquire the data they need to support ecodesign activities. Through a survey of industrial practitioners, Bey et al. (2013) identified that companies often struggle to find the information and data they require on environmental impacts of their materials and components. Furthermore, they struggle to find information on alternative materials and components that might result in a reduction in the life cycle environmental impact of the product being developed.

All challenges in the *knowledge* category therefore concern: the environmental information, knowledge, expertise and data required for ecodesign.

4.2 The initial framework

Table 3 presents the initial framework with the categories, themes and sub-headings which were developed from the literature summarised above. The table was then used in block 2 of the semi-structured interviews. It is worth noting that the wordings of the sub-headings were subsequently edited to reflect the interview data more accurately and improve the analysis across the cases. However, the most important modifications to the framework are described in section 4.3.2. These were all in the form of new sub-headings; no edits were made to the categories and themes. Table 4 contains the new sub-headings created. For clarity, only the final wording of the subheadings is used in both tables 3 and 4.

The complete final framework can be constructed from table 3 and 4 together. To facilitate access and use by other researchers, the final framework has also been published at http://www.ecodesign.dtu.dk/-/media/Sites/ecodesign/2014 version/ChallengesEcodesign.xls. The final framework brings together **all** the challenges identified from the literature review and the case study interviews. It still contains the three sub-headings that were not mentioned by any of the companies in our sample as they may yet provide useful prompts in further work.

Category	*Theme*	*Sub-heading*	*Recurrence*[7]
1. Strategy	1.1 Building the business case and gaining senior management commitment	1.1.1 Identifying the business drivers	2
		1.1.2 Lack of senior management commitment/support	5
	1.2 Developing a long-term strategy	1.2.1 Developing and updating strategy over time	4
		1.2.2 Poor integration into management and corporate strategy	5
2. Tools	2.1 Finding the right tool for ecodesign implementation	2.1.1 Lack of criteria for selecting the most suitable tools	1
		2.1.2 Difficult to implement new tools within the development process	4
	2.2 Problems with applying existing tools	2.2.1 Difficult to use the results of an LCA to inform the decision-making process	4
		2.2.2 Completing an LCA requires too much resource in terms of data, time, and expertise	2
		2.2.3 Support for data exchange between different tools is lacking	1
3. Collaboration	3.1 Internal Collaboration	3.1.1 Need for multidisciplinary and multi-department approach	5
		3.1.2 Difficult to use ecodesign knowledge to support decision making across different functions	0
		3.1.3 Difficult to involve key stakeholders in the early stage to create trust and ownership	0
	3.2 External Collaboration	3.2.1 Identifying the stakeholders from the value chain to include in the ecodesign effort	6
		3.2.2 Changing the type of interaction in the value chain from transactions to collaborations	4
4. Management	4.1. Integration with New Product Development	4.1.1 Difficult to integrate ecodesign activities into the product development process	4
		4.1.2 Difficult to manage expectations within development projects	0
		4.1.3 Lack of a systematic approach to the implementation of ecodesign throughout the company	2
		4.1.4 Lack of deployment of roadmap for continuous improvement	1
		4.1.5 Difficulty to integrate environmental issues very early in the development process	2
		4.1.6 Lack of environmental impacts as a global target	1

[7] 'Recurrence' means the number of companies that mentioned this challenge.

	4.2. Managing requirements	4.2.1 Difficult to take decision when there are trade-offs between environmental issues and the other aspects (such as cost, quality, security...)	5
	4.3. Resource allocation	4.3.1 No extra resources allocated to new ecodesign initiatives	4
		4.3.2 No extra time allocated to new ecodesign initiatives	2
	4.4. Organisation and structure	4.4.1 Difficult to know which department should house the ecodesign implementation activity	3
5. Knowledge	5.1. New knowledge and expertise need to be developed in the company	5.1.1 Communication among people with different expertise is difficult	4
		5.1.2 Requires a large amount of knowledge development both within the design department and the supporting business functions	2
		5.1.3 Staff do not have the level of environmental knowledge required for effective ecodesign	5
	5.2. New types of data required	5.2.1 Difficult to find the environmental impact data required for ecodesign	2
		5.2.2 Difficult to find alternative materials/components that would have a lower environmental impact	3

*Table 3. Categories, themes and sub-headings in the **initial** framework - showing the number of companies mentioning each challenge.*

4.3 Cross-case analysis

In the following sections, the results are analysed at three different levels of detail: sub-heading level (which shows the results directly linked to interview transcripts), theme level and category level (which provides an overview of how many times each category of challenge was mentioned by the participants).

4.3.1 Cross-case analysis at the sub-heading level

Table 3 shows the challenges mentioned by the companies classified at the sub-heading level. The table shows the total number of companies mentioning a challenge in order to identify the most recurrent challenges in the nine case study companies (C1 to C9). For each of the five categories, the most recurrent sub-headings are discussed in detail. They serve as examples to show the depth of analysis that has been conducted.

Sub-headings in the *strategy* category

"Poor integration into management and corporate strategy" (1.2.2) was cited as a challenge by five out of the nine companies. The data showed that the poor integration of the environmental topic into management and corporate strategy was caused by the missing link between the department who coordinates the environmental improvements effort and the corporate strategy definition (C1, C4, C7, C8). In some instances, this missing link is caused by a difficulty to communicate the results from ecodesign efforts to corporate strategy developers (C4, C8).

"Lack of senior management commitments/support" (1.1.2) was also cited by five companies and has been described by C7 as a lack of endorsement by the top management that creates difficulties to get a consistent support over time. This 'lack' was expressed by other companies in terms of: lacking resources (C4); low prioritisation of environmental requirements (C1); or lacking firm commitment from top management (C3, C8).

Sub-headings in the *tools* category

"Difficult to implement new tools within the development process" (2.1.2) was one of the challenges cited by four out of the nine companies. The data showed that implementing tools into the design process is difficult because, typically, the tools used to support ecodesign are expert tools and used in post-design activities (C3, C8). Even when customised tools are developed it is difficult to test them in real design conditions (C4) or to identify the best approach to implementing them in the design office (C7).

The other frequently mentioned challenge related to tools was that it is "difficult to use the results of an LCA to inform the decision-making process" (2.2.1). With LCA, it is difficult to translate its results into "simple language" to take decisions (C1, C8), or to develop solutions (C4). C7 is limited by the fact that there is no Life Cycle Inventory relevant for its geographical zone (Brazil) making the results inaccurate for decision making.

Sub-headings in the *collaboration* category

"Identifying the stakeholders from the value chain to include in the ecodesign effort" (3.2.1) was the most recurrent challenge within this sub-heading and was cited by six out of the nine companies. Of those companies, C4 and C7 suggested suppliers need to get involved in the environmental improvements of their activities - C7 mentioned a particular difficulty making design agencies integrate environmental constraints in their proposals. Other companies suggested that new suppliers are needed to support the development of innovative solutions (C5, C6).

Additionally, "Changing the type of interaction in the value chain from transactions to collaborations" (3.2.2) was cited by four out of nine companies and refers to challenges regarding moves toward more collaboration (C3,C9). This change is described by C3 as moving from having "sub-contractors" to "collaborators" in the supply chain. Another difficulty experienced by C2 and C7 is how to formalise the environmental constraints for suppliers. C2 did this by adding requirements to the contract but they recognised that this was not really 'collaborating'.

Sub-headings in the *management* category

There are a large number of challenges that can be classified as management issues. The total number of quotes in this section is the largest (35 in total, see Figure 2). As an example, five out of nine companies mentioned "Difficult to take decision when there are trade-offs among environmental issues and the other aspects (such as cost, quality, security...)" (4.2.1). Cost is still the main driver in NPD activities and it is very difficult to implement an ecodesign solution that is not cost-effective (C6, C7, C8). As soon as ecodesign is challenged by other trade-offs the solutions stop being supported by developers (C1, C4).

Sub-headings in the *knowledge* category

The most recurrent challenge in the 'knowledge' category is "Staff do not have the level of environmental knowledge required for effective ecodesign" (5.1.3), which was cited by five out of the nine companies. This lack of knowledge can take different forms in the different company structures. For C6 and C7, the knowledge needed for ecodesign is missing, incorrect or vague. In C6 for example, they still have to fight some of the preconceived ideas held by staff, such as that considering the environment will always result in higher manufacturing costs, or that recycled materials are of poor quality. C7 struggles with the definition of a common lexicon for ecodesign principles. In C1, the challenge is that designers are not aware of the environmental impacts that result from the decisions they are making. For C2 and C3, the lack of a "recipient/actor" for environmental knowledge is perceived as a challenge for ecodesign.

4.3.2 Enrichment of the challenges framework

The initial framework based on the literature review was helpful in eliciting responses on the challenges faced by the case study companies. In this data set, three sub-headings were never mentioned and 13 new sub-headings were identified. All the new headings are shown in Table 4. These represent our additions to the existing literature on the challenges currently faced by companies in their ecodesign implementation activities. Only the challenges mentioned by three or more companies are discussed below.

In the *tools* category three new challenges were added. Despite the common belief that we have enough tools (Baumann et al., 2002), four companies mentioned a lack of tools support on specific issues, that have been classified under the new heading "Need for new tools" (2.1.3). Whether those issues are company-specific or common among other organisations needs to be explored in more detail, but four companies have identified potential functionalities where tools might be needed. The functionalities participants felt were missing from their existing tools were: evaluating raw materials stock (C9); supporting the knowledge development process on ecodesign issues and educational tools (C8); provision of information in CAD systems on the environmental impact of the authorized materials[8] (C6); traceability of the environmental information for marketing purpose[9] (C5).

Within the *collaboration* category four new challenges were added (two about internal collaboration and two about external collaboration). The most recurrent new challenge identified was "Difficult to raise internal awareness for ecodesign implementation" (3.1.4). For some, like C6, it is a matter of jumping on every opportunity to engage in ecodesign discussion. For others, like C4, it is about changing the internal narrative within the company because it has become so positively biased (selectively highlighting areas in which the company is making progress on environmental challenges whilst ignoring less favourable topics) that designers have become cynical and are disengaging from the topic.

[8] The automotive sector are only allowed to use pre-validated materials grade. Identifying the environmental performance of each grade could support designers when dimensioning their systems in CAD.

[9] According to C5 there is a need for tools that can help to answer the question "how to make it [information used in decision-making] traceable, how to make the end consumer trust what we do and why we do it".

Category	*Theme*	*New sub-heading*	*Recurrence*
1. Strategy	1.1 Building the business case and gaining senior management commitment	None	
	1.2 Developing a long-term strategy	1.2.3 Lacking effective prioritization process to ensure the projects that will deliver the greatest business value and environmental benefit are implemented	1
		1.2.4 Difficult to keep the momentum for ecodesign implementation	1
2. Tools	2.1 Finding the right tool for ecodesign implementation	2.1.3 Need for new tools	4
	2.2 Problems with applying existing tools	2.2.4. Difficult to achieve the behaviour and cultural changes necessary to support tool implementation	1
		2.2.5 Difficult to find the right balance between simplification of the LCA approach and potential loss of accuracy/reliability/quality	1
3. Collaboration	3.1 Internal Collaboration	3.1.4 Difficult to raise internal awareness for ecodesign implementation	3
		3.1.5 Responsibility for ensuring that ecodesign objectives are achieved is not clearly allocated to individuals/teams	2
	3.2 External Collaboration	3.2.3 Difficult to raise external awareness for ecodesign implementation	2
		3.2.4 Transparency of environmental data in the value chain	1
4. Management	4.1. Integration with New Product Development	4.1.7 Lack of motivation/resistance from internal stakeholders for ecodesign	5
		4.1.8 Problems fitting with timescales of NPD process	2
	4.2. Managing requirements	4.2.2 Difficult to manage customers' requirements for ecodesign	3
	4.3. Resource allocation	None	
	4.4. Organisation and structure	4.4.2 Difficult to implement new business models	1
5. Knowledge	5.1. New knowledge and expertise need to be developed in the company	None	
	5.2. New types of data required	None	

*Table 4. **New** sub-headings in the framework and number of companies mentioning each challenge.*

Four new challenges were added within the *management* category. The most notable of these is "Lack of motivation/resistance from internal stakeholders for ecodesign" (4.1.7) mentioned in five out of nine companies. However, the lack of motivation within the company seems to be present in different departments. For C3, they state that the organisation is "too much in problem resolution attitude" rather than supporting actions toward ecodesign. The same can be found at C7 where designers are on board with ecodesign but some stakeholders are still questioning the information and results provided for environmental decision making. For others, like C6, it is the other way around, the strategy is clear but the design teams disregard it because they think environmental features are not demanded by consumers. For C2, it is not so much a lack of motivation but rather a resistance to change the way the product is designed and reluctance to get out of their comfort zone. To summarise, the lack of motivation is often due to a specific department in the company not being on board with ecodesign (although which department varies) and to a reluctance to embrace the tools and support systems developed for ecodesign.

4.3.3 Cross-case analysis at the theme level

The results of the cross-case analysis at the theme level are presented in Figure 1. Of the 12 themes within the analysis framework five of them were mentioned 10 or more times. These five are each discussed in order of recurrence in the paragraphs below in order to draw out the more generic challenges faced by manufacturing companies for ecodesign implementation.

Integration with New Product Development (17 mentions across seven of the companies).
By studying these mentions, the general underlying cause appears to be the resistance from certain departments to ecodesign implementation (as discussed in the previous section), and not knowing how or where to incorporate ecodesign into the formal NPD process.

Figure 1. Recurrence of challenges mentioned by theme.

Ecodesign requires additional external collaboration compared to conventional design (14 mentions across seven of the companies). Again, the detailed data shows that the main issues are that ecodesign requires collaboration with suppliers and that companies are finding it difficult to identify the right suppliers and ensuring that they are willing to engage in real collaboration on this topic. The core of this challenge seems to be the difficulty in making a shift in the supplier-client relationship from one based on simple, transactional interactions, to a more complex, interactive, strategic relationship.

Developing a long-term strategy (11 mentions across seven of the companies). This theme was related to the challenge of developing and updating the strategy over time and how to integrate ecodesign into strategy. It seems that several of the companies have included ecodesign and environmental goals within their corporate strategy but they do not really know at this stage what they want to achieve or have a clear vision of what the firm should be doing in terms of environmental sustainability. Common 'disconnects' were that: those involved in formulating strategy do not understand the company's current sustainability performance or the best way to make progress on key environmental issues; and operational-level staff do not understand the strategic drivers.

New knowledge and expertise need to be developed in the company (11 mentions across seven of the companies). A key issue here is that the majority of staff within the companies do not have an understanding of ecodesign concepts and terminology. This then makes it difficult for staff that are working on ecodesign activities to communicate with their colleagues about what they are doing, why it is important and what actions need to be taken. Several companies also noted a need for one or more ecodesign experts to provide the knowledge and competencies required to support ecodesign implementation within the company. The cost of this resource and the difficulty of finding people with the right set of knowledge and skills in the workforce were also mentioned as challenges.

Ecodesign requires additional internal collaboration compared to conventional design (10 mentions across eight of the companies). The findings here seem to reinforce some of those previously mentioned. Specifically, collaboration required across functions and departments may contribute to the communication challenges noted earlier. Also, the challenge of raising awareness amongst internal colleagues seems to be linked to the internal motivation/resistance issue noted under the integration with NPD theme.

4.3.4 Recurrences at the category level across the cases

This section shows the overview of the whole data set by looking at the categories, this provides a short summary. In total, 111 challenges for ecodesign implementation were mentioned by the nine case companies. An average of 12.5 challenges per company with a maximum of 18 challenges and a minimum of seven challenges cited by each company.

Figure 2 shows that *management* is the category with the highest recurrence of challenges (35 challenges), followed by *collaboration* (23 challenges), *strategy* and *tools* (both with 18 challenges each). *Knowledge*, with 16 challenges, is the least frequently mentioned category.

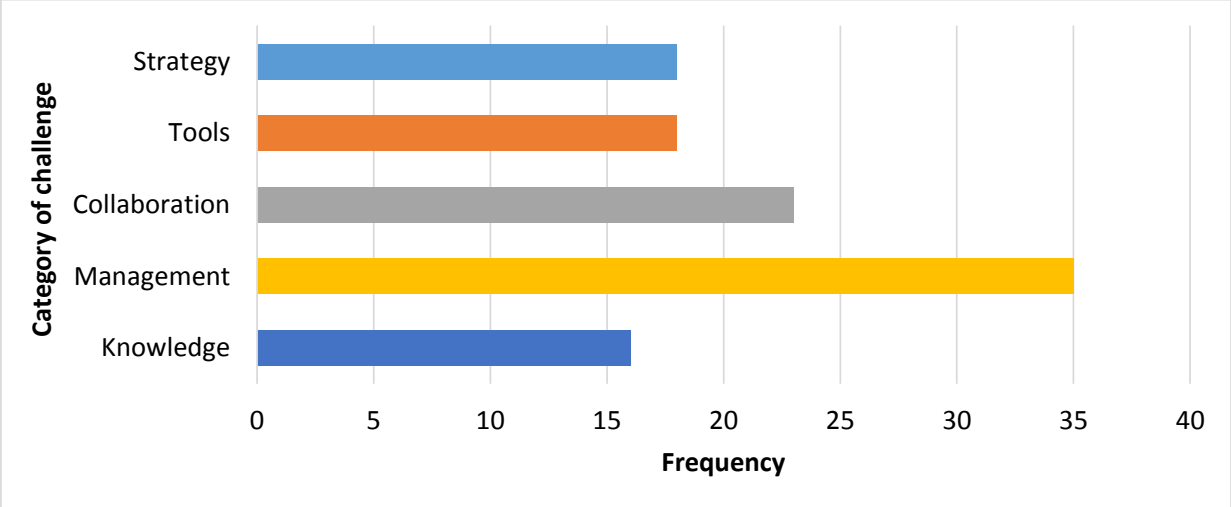

Figure 2. Recurrence of challenges mentioned by category.

4.4 Participants' ranking of the challenges compared to the ranking from the interview data

In the final part of the interviews, participants were asked to rank the importance of the challenge categories in the framework. The aim of this task was to understand to what extent the results of the analysis in terms of the recurrence of challenges mentioned by the participants correlated with the interviewees' subjective view on which challenges they considered to be most important. This analysis does not allow us to determine which categories of challenge are objectively the most important, but it does help to check if the researcher's interpretation of the data is aligned with the views of the participants.

We defined 'important' as those challenges that are both of high priority/urgency (need to proceed or tackle something before others) and high criticality (of decisive importance). In practice, these two aspects - if they had been treated separately in the protocol - would have led to different rankings. However, the impression of the interviewers was that the majority of interviewees ranked the challenges according to criticality rather than priority/urgency.

Figure 3 provides a consolidated overview of the interviewees' ranking of each category of challenge. A ranking of one indicates the challenge category of highest importance, five indicates the least important. The categories are ordered from top to bottom by the proportion of cases giving that category a number one ranking, then by proportion of number two rankings, and so on. This overall ranking of the categories suggests that, according to the interviewees' opinions, *management* is the most important category of challenge, and *tools* is the least important category.

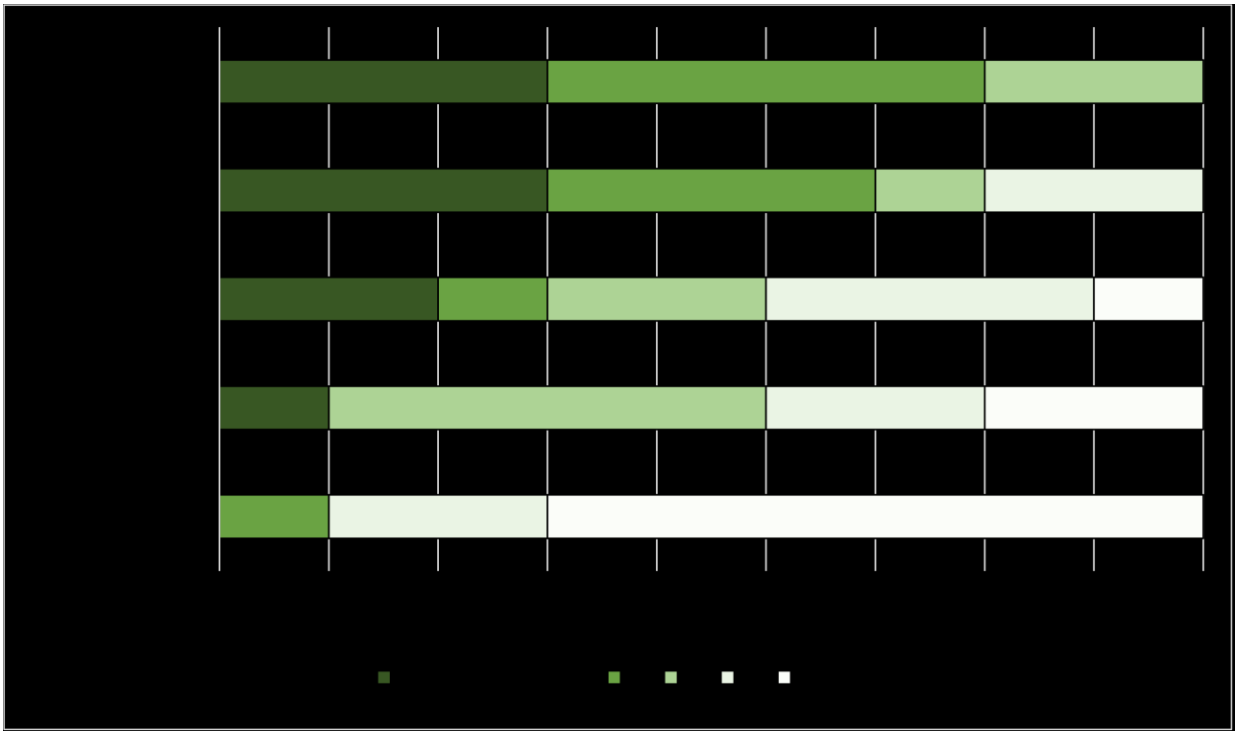

Figure 3.Overview of interviewees' subjective ranking of the relative importance of each of the categories.

When the overall category rankings (from Figure 3) are compared with the recurrence of challenges mentioned by participants in their interview (from Figure 2). We can see a reasonable agreement between these data sets. In both, *management* challenges are more prevalent.

Strategy challenges were ranked second by the interviewees whilst only equal third in the data analysis. However, when looking at the quotes, it is clear that some of the challenges they perceived as strategic have more to do with the management of activities - albeit at the strategic level of the company. These were therefore coded by us as *management* challenges, thereby creating a bigger difference between those two categories (*Management* and *Strategy*).

The second disparity is where *collaboration* has the second highest count in the data analysis whilst only third in the ranking by the interviewees. In our coding we were able to attribute several quotes, which superficially could be perceived to be about a lack of knowledge within the company, to a lack of adequate collaboration between the departments. This explains the higher ranking of the *collaboration* category in the data analysis shown in Figure 2.

The *tools* category was ranked lowest by the interviewees partially because of the limited definition of that category in the ranking exercise (defined in the final part of the interview as: *finding the right tools and implementing them*). Interviewees felt the challenges associated with tools today are in terms of training, knowledge and willingness to use them for design, these were still attributed to tools in the data analysis thereby placing it slightly higher in Figure 2.

Overall, this additional analysis helped check the approach taken when coding the data. The outcomes are close enough to show adequate shared understanding between the researchers and interviewees of

the challenges at the category level, whilst the detailed analysis of the interview data at the sub-heading level (presented in sections 4.3.1 and 4.3.2) is more granular and yields the main findings for the paper.

5. Discussion

This section discusses the overall implications of the work. Sections 5.1 and 5.2 draw together the new findings which focus on the first research question - identifying the challenges faced by manufacturing companies for ecodesign implementation. Section 5.3 addresses the second research question by discussing the value of the framework to help consolidate future research in the field.

5.1 Comparison with similar studies

This section compares our main contributions with the most relevant studies which have also identified challenges faced by manufacturing companies for ecodesign implementation.

The work by Bey et al. (2013) is probably most closely related to this study. They found that 'knowledge' related challenges, such as "difficulty in finding environmental impact information" and "too much specialist knowledge required" were the most commonly cited issues in their international survey of 80 companies. There were similarities in the specific findings, such as: the lack of additional time and resource allocated to ecodesign being high-ranking challenges; and problems with tools being a low-ranking challenge. The contribution of our study relative to that of Bey et al. is the use of a more comprehensive framework of challenges, which led to the identification of more challenges related to strategy and management.

In a study of ecodesign implementation among Swedish automobile manufacturers Poulikidou et al. (2014) identified a number of barriers to ecodesign implementation through interviews with staff. Our study corroborates several of the barriers identified by Poulikidou et al., including difficulties in cross-department communication; resistance to introducing ecodesign activities from operational level staff; lack of time; and the observation that environmental criteria are often given a low priority when faced with a trade-offs against traditional design criteria (e.g. cost, quality and performance). The contribution of our study relative to that of Poulikidou et al. is the quantified data on the recurrence of challenges across the sampled companies. For instance, the study by Polikidou et al. devotes significant attention to the use (and development) of tools within the ecodesign activity, as have many other studies (Baumann et al., 2002; Bocken et al., 2012; Knight and Jenkins, 2009; O'Hare et al., 2010; Tyl et al., 2014). The finding from our study, that tool-related challenges are not as recurrent as management and collaboration-related challenges, suggests there may be a need to re-evaluate the research priorities within the ecodesign community.

O'Rafferty (2012) provided a comprehensive literature review of ecodesign implementation challenges for SMEs and has identified 28 challenges which were categorised against the headings of 'strategic' (seven challenges), 'operational' (three challenges), 'managerial' (nine challenges), and 'external' (nine challenges). The high number of managerial challenges and the relatively low number of operational challenges is consistent with the results of our study and shows several similarities in terms of the specific issues identified e.g. "Lack of managerial and operational resources (including time, cost,

skills).” A notable difference is the prevalence of the ‘external’ category in O’Rafferty’s review. However, this category included challenges such as “competing policy rationales (e.g. environment vs innovation)” which were not included within the scope of our study as policy was considered to be outside the scope-of-influence of the industry practitioners. The contribution of our study relative of that of O’Rafferty is that it is based on recent (2014) data compared to the older (1999-2004) sources used within the O’Rafferty review. His findings are similar in this case, but assumptions about current industry needs and challenges need to be checked regularly to ensure that research delivers up-to-date, valuable, relevant findings and recommendations for industry practitioners.

By comparing the results of our study to previous studies we have been able to identify a number of similarities with previous findings, and have also defined the novel contributions of this study, which are:

- the use of the framework of ecodesign implementation challenges led to the identification of more challenges, particularly in the categories of strategy and management;
- the quantified data on the recurrence of the challenges identified, which showed that tools-related challenges recur less frequently, whilst continuing to receive significant attention from the ecodesign research community;
- where results are similar to previous studies, our up-to-date primary data from industry helps to confirm which ecodesign research remains relevant to industry.

5.2 Detailed findings on the challenges for ecodesign implementation and future work

This section looks more closely at the most interesting findings on the challenges themselves and proposes further work based on those.

It was noted earlier within the *management* category the most frequently mentioned challenges were integrating ecodesign activities into the NPD process and a lack of motivation, or even resistance, to ecodesign among staff. The problem of integration of ecodesign activities within the NPD process has been noted on many occasions (Bakshi and Fiksel, 2003; Dangelico and Pujari, 2010; Johansson, 2006; Le Pochat et al., 2007; Luttropp and Lagerstedt, 2006). The most common response to addressing this challenge is to propose new process models for ecodesign or new tools. However, it may be that efforts should instead focus on understanding why operational staff are not motivated, or even resistant, to engage in ecodesign activities. The pioneering work by Verhulst and Boks (2014, 2012) seems like a promising approach to address this type of challenge as it has applied theory and good-practice from the domain of organisational change management to build a better understanding of the role of human factors in ecodesign implementation.

Collaboration was the second most common category of challenge mentioned by the case study companies. This related to the additional need for both internal and external collaboration that ecodesign demands. The challenges of internal collaboration might also benefit from the change management approach mentioned above. Concerning external collaboration, the need to change the nature of the supplier-client relationship from one based on simple, transactions interactions to one based on more in-

depth engagement and collaboration seems to be a common challenge. This type of challenge has been studied for many years within the 'green supply chain' literature (Walton et al., 1998) and therefore some useful insights for further work may be found in that domain. In addition, there have been some recent attempts from within the engineering design and ecodesign communities to address the challenge of ecodesign collaboration with suppliers. For instance, McAloone et al (2010) have suggested that during the front-end of innovation activities companies should re-conceptualise their relationships with suppliers from the traditional, sequential supply chain to a 'value star' (Normann, 2001 in McAloone et al 2010) in which companies collaborate with multiple key suppliers in order to create value for the end customer. Similarly, Mombeshora et al. (2014) have adopted three-dimensional concurrent engineering (3DCE) (Ellram et al., 2007 cited in Mombeshora et al, 2014) - which aims to integrate the consideration of product design, process design and supply-chain design - as a potential approach to improve the results from ecodesign activities. The integrative nature of 3DCE is promising for this type of complex, cross-disciplinary challenge and merits further research.

Finally, concerning *strategy* it was noted that there is a common challenge in embedding a long-term business strategy that incorporates environmental considerations and ecodesign. A specific issue related to communication between operational-level staff and senior management was identified as a contributory factor to this challenge. This shows similarities to the findings of both Handfield et al (2001) and Boks (2006), who found that "Too big a gap between ecodesign proponents and those that have to execute it" was a common challenge for companies. The difference compared to our finding is that the focus of the previous two studies was on the impact at the operational level, whereas in our study the interest focuses on the impact at the strategic level. Either way, better two-way communication appears to be the solution to these problems. One solution might be to appoint ecodesign champions, who have the potential to bridge the communication gap between the strategic and operational levels according to Brezet and van Hemel (1997). This suggestion has been around for a long time but few comprehensive studies on that approach exist and it therefore warrants further research.

5.3 Value and future use of the framework

The literature review at the start of this collaborative research showed that there was a need for a common framework to enable: comparison of the findings from a specific company with other companies; comparison of the findings of any new study with previous research; or comparison of before-and-after interventions of ecodesign in industry. The research methodology describes how the research was conducted in order to propose, test and iterate such a framework. In the testing stage, the paper has presented the use of the framework for in-depth interviews in companies with significant experience of ecodesign. The first iteration of the framework as a consequence of these cases is presented as one of outcomes from the research. This involved the addition of new challenges that were mentioned in the case studies but which were not initially identified in the literature review as well as enhancements to the robustness of the proposed framework as a tool for research by adjusting the wording and vocabulary.

To address the second research question, the research has shown that it is possible to structure the challenges for ecodesign implementation in the form of a framework. The nine cases presented showed that such a framework can help to systematically illicit new challenges and make more robust the cross-

case comparison. All three levels of the framework (categories, themes and sub-headings) provided useful insights whilst at the sub-heading level the most detailed findings for further research emerged. Furthermore, our discussion shows that the framework supports the comparison with previous studies and thereby can consolidate the research in the field more generally.

On this basis, the results suggest that the framework can provide a useful tool for the research community going forward. The framework is publicly available at http://www.ecodesign.dtu.dk/-/media/Sites/ecodesign/2014 version/ChallengesEcodesign.xls and can be used to design both larger quantitative studies and in-depth qualitative studies such as the one presented here.

6. Conclusions

This paper set out to highlight the most common challenges faced by industry in the implementation of ecodesign today. This was achieved by, proposing a framework to structure the research, and subsequently, testing and iterating the framework using the nine in-depth case studies. The framework consists of five main categories of challenge which were identified from the literature: strategy, tools, collaboration, management and knowledge. Using this framework has helped to understand how common these different categories of challenges are and to identify some new challenges not previously mentioned in the literature. The framework itself provides a methodological contribution to the research community in that that it can be used in further research as a basis to design both large quantitative studies and in-depth qualitative studies. The framework has shown to help cross-case comparison within studies and with previous studies.

From the case studies, *management* was found to be the most recurrent category of challenge but it is clear that there are challenges across all departments and levels of the companies investigated. At the strategic level, *developing a long-term strategy* is the most common challenge with companies still struggling to integrate ecodesign into management and corporate strategy and finding it difficult to develop and update strategy over time. Within *management*, the most recurrent challenges are: the lack of integration of ecodesign activities into existing NPD process; prioritising it against other trade-off such as costs; and the lack of motivation/resistance from internal stakeholders for ecodesign. There are also a variety of challenges at a very practical level related to collaboration, tools and knowledge. In ecodesign today, the activities need to extend to the entire value chain and therefore new challenges are associated with external stakeholder collaboration. Internal challenges continue to include issues such as: tool integration (including LCA); the evolution of tool requirements; internal communication; and dissemination of the internal knowledge, competences and expertise needed for ecodesign.

Regarding limitations of the study, the small sample of companies enabled us to analyse the challenges qualitatively, giving the opportunity to identify how this broad range of companies experienced and tackled ecodesign implementation challenges. The study provides a rich picture of these challenges. The sample size was not big enough to assess whether certain challenges are associated with particular industries or business contexts. Neither is the sample large enough to analyse the relative importance of the challenges identified, which would ideally be completed with robust statistical analysis.

As regards implications and further work, comparing the results against the literature showed that challenges identified decades ago are still very real for many of the companies in our study. Some

challenges have been updated or made more explicit through this study. New challenges have also been included that provide a broad range of stimuli for further research. Some examples of research ideas include: exploring supply-chain collaboration to improve ecodesign results; testing theories from change management to improve motivation for implementation; and investigating the use of champions to improve two-way communication between strategic and operational levels.

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Appendix

C1 is a large manufacturing company in the healthcare sector. Their ecodesign efforts started 12 years ago with elimination of hazardous substances in existing products and a focus on improving their packaging. Like many companies they then moved onto ecodesign across a range of products. They then integrated ecodesign into all product development processes and started using 'environment' actively in sales. What is unique about this case study is the level of ecodesign integration across the whole business: delegating the responsibility from the environmental experts to actual decision makers in the design process. Particular initiatives affecting the near future are around increasing awareness in Research & Development: e.g. ecodesign KPIs as part of R&D KPIs.

C2 is a large company with employees of over 20 nationalities. Their ecodesign efforts started in 2011 when they were driven predominantly by increasing environmental legislation, demands from their European customers and commitments from their industry sector. What is unique about their ecodesign approach is that they also support development projects beyond their immediate products into their entire value chain: e.g. engaging their suppliers to design more eco-friendly components. Currently, they are also looking at how their products might use renewable energy sources. For the immediate future they are focusing on chemical- and materials- compliance, recycling and end-of-life issues.

C3 is a lighting company founded in 1997 with 50 employees. The company consists of a young and dynamic team that brings together skills from design to marketing, through to production and manufacture. Integrating environmentally-friendly technologies to create efficient and innovative products is natural to this young team, and core to their activities. What is interesting about this ecodesign case study is that they have chosen to make environmental considerations part of quality control. Within quality control their approach started with work on their products' LCAs and then implementing ecodesign strategies. Going forward their projects seek to balance: aesthetics, performance, costs and the environment.

C4 is one of the largest companies in the world within its sector. They have a particularly long track record in ecodesign, starting 20 years ago when they performed their first life cycle assessment was performed, which led to a clear strategic direction in the company. As others in our sample, the main environmental impact of their products is energy consumption during the use phase, therefore ecodesign efforts have focused on developing and marketing energy efficient products. Legislative compliance and their supply chain also influence their ecodesign effort, and the company have actually been able to actively influence legislative requirements. What is unique about this case is that they are currently expanding the application scope of their ecodesign activities to include other sustainability aspects including social, ethical and financial aspects of product development and other business processes.

C5 started in the nineteen eighties as a small company producing environmentally-friendly toys. They are now an international company selling products in more than fifty countries. What is unique about this case study was that the company was founded on the principle of producing more sustainable products. Historically, their efforts have been focussed around the use of environmentally-friendly materials. Today they are focusing on the zero waste philosophy, working on finding new purposes for by-products of the manufacturing process. For the future, their initiatives expand to a broader

commitment to sustainability, including for example looking at the social implications of toys as a learning support for sustainable values.

C6 is a large multinational car company therefore legislative compliance has focused their efforts on tail-pipe emissions reductions (engine developments) and design for end-of-life recycling of the whole vehicle. The company set-up their internal environmental team 10 years ago. What is unique is that this company is that they are regularly a target for outside scrutiny concerning the sustainability performance of their products as they produce large luxury vehicles. Also interesting is, that even though this company has a corporate environmental sustainability strategy, their environmental team was founded as a 'bottom-up initiative' from existing employees. Gradually the ecodesign and sustainability initiatives are broadening to include: ideas for changing their business model (looking at the future for "mobility" solutions); and making life-cycle thinking routine in the business/design units. For the immediate future they face increasingly difficult technical ecodesign challenges but also adjusting their brand image to reflect their ecodesign efforts.

C7 is in the chemical sector with a strong eco-friendly image and recognition for its sustainability efforts. The systematic implementation of ecodesign in the company started in 2011, but many smaller initiatives were observed since 2001. What is unique about this case study is that sustainability and innovation are together the strongest drivers for product development, whilst cost reduction takes a lesser role. Current focus is on company-wide implementation of ecodesign tools. Their technical ecodesign approaches are novel (such as the implementation of Biomimetic principles) and far reaching such as (R&D around the availability of recyclable materials in the supply chain).

C8 is a large automotive company whose environmental efforts have been focused around legislative compliance. In nearly twenty years, they developed strong ecodesign skills partly due to regulation pressure and the need to anticipate future regulations. Within the company, they originally had dedicated ecodesign practitioners mainly in R&D and in the materials department, but some in other product development services also. What is unique in this case study is the current view, that a large number of their people are involved in design projects where environmental constraints are quite strong due to regulative regulatory pressure. Future efforts focus on developing and defining solutions for their products' end of life definition.

C9 is the smallest company in our sample. They produce high-performance textiles for national and international markets in roughly equal proportion. In general, the textile industry started to work on resource consumption, material loss and water use around 15 years ago, without calling it ecodesign. The current director started actively investing in ecodesign activities 5 years ago for both personal and business reasons (such as the potential for environmental labelling of their products). Leadership plays a large role in SMEs and in this case, the director is the main driver for ecodesign activities, with support from the technical director. Current and future projects include the development and launch of eco-innovative products and the use of life cycle assessment for marketing purposes.