Journal of Cleaner Production 279 (2021) 123520

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Effective ecodesign implementation with the support of a lifecycle engineer

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A R T I C L E I N F O

Article history:
Received 7 April 2020
Received in revised form
19 July 2020
Accepted 28 July 2020
Available online 9 August 2020

Handling editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Specialist
Knowledge
Domain
Engineering design
Environment
Sustainability

A B S T R A C T

In the field of Ecodesign, in which the answers to the questions of "why", "what", and "how" have been largely studied in the past, the lack of implementation in industry remains an issue. The literature lacks insights into the "how" question combined with "who" for ecodesign implementation. The aim of this paper is to propose a concept for a knowledge holder, called a lifecycle engineer, with specific knowledge that can support a team or organization in the ecodesign process for its more effective implementation. This is achieved first by a literature review using a set of constructs derived from theories of engineering design and transdisciplinary research. Second, by consulting the results from the literature review and the proposal of a lifecycle engineer, through semi-structured interviews, with practitioners from the manufacturing sector. The analysis of the semi-structured interviews shows that the relevant knowledge includes lifecycle analysis, materials and their selection, energy efficiency, legislation, and management. This knowledge was complemented by skills that practitioners thought of as relevant for effective implementation. Moreover, the proposal of a lifecycle engineer, according to most practitioners, was found to be useful. The advantages of a lifecycle engineer include having more focus on ecodesign and the availability of information and staff to drive changes. Caveats include clear benefits against investment for the company, especially for smaller ones, and enough tasks for full-time employment.

1. Introduction

Ecodesign[1] is defined 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 14006, 2011 pp.2).[2] Ecodesign, as defined above, involves two components: information processing for problem solving and the implementation of the information processing in the activities of an organization.

The extant literature informs that much effort and resulting insight in the academic ecodesign community has focused on processing information in ecodesign under the name of ecodesign methods (e.g., Bovea and Pérez-Elis, 2012; Rousseaux et al., 2017). On the other hand, ecodesign in industry remains limited in its practical and effective implementation[3] (e.g., Dekoninck et al., 2016; Lamé et al., 2017; Rossi et al., 2016). For instance, Dekoninck et al., (2016) report that lack of knowledge in staff is a challenge for ecodesign implementation. This, in turn, can result in ineffective requirement specification and unnecessary iterations (see Handfield et al., 2001). This is in contrast to some success in implementing environmental management systems (see Fonseca and Domingues, 2018). For effective ecodesign implementation,

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[1] In this article, the word ecodesign is capitalized when referring to the area in the literature. When referring to ecodesign as a design activity, it is not capitalized.

[2] ISO 14006:2020 offers the definition of ecodesign as a "systematic approach that considers environmental aspects in design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product" (pp. 3.) However, the definition from ISO 14006:2011 presents a closer representation to the authors' understanding of Ecodesign knowledge as presented in the literature and ecodesign practice as a design activity.

[3] Effective implementation is understood here as possessing and applying the necessary knowledge to implement environmental aspects in the product development process of an organization.

https://doi.org/10.1016/j.jclepro.2020.123520
0959-6526/

manufacturing companies need to change their design practices, which often means industrial insights of dos and don'ts and “no more tool development!” (Boks and Stevels, 2007, pp. 4038).

Designers[4] in manufacturing companies are essential but face increasing requirements (see Buchert et al., 2017). The environmental issue has been just one of the many aspects that a designer is expected to address properly (Luttropp and Lagerstedt, 2006); safety, cost, quality, and legal issues are such examples that are often prioritized before environmental aspects (Poulikidou et al., 2014). Today, the situation is even more difficult: more products are connected in use and expected to have embedded intelligence, and thereby new functions are being designed for products. This has created the need for designers to master new capabilities (Tomiyama et al., 2019). Further, the trend is a shorter lead time to market launch (Albers et al., 2017) and an expanded scope of design objects to larger systems (even a system of systems) (Haskins et al., 2006; Lindemann, 2011). All these circumstances make it even more difficult for a designer to take care of the environmental issue by himself or herself, and hence motivate a reconsideration of how to implement ecodesign effectively in the future.

In general, for research and practice of engineering design, which ecodesign belongs to, knowledge transfer from theory to practice is a huge challenge historically (see Andreasen, 2011) and based on recent research (see Gericke et al., 2016). Also, properly carrying out ecodesign, for example, by following a certain method, requires specific domain knowledge. However, research of knowledge on ecodesign for improving ecodesign implementation is scarce (except a few exceptions; see Boks and Stevels, 2007), in contrast to abundant research effort on methods (see Rousseaux et al., 2017). When viewing Ecodesign research as a transdisciplinary (TD) research (see Sakao and Brambila-Macias, 2018) with engineering design and environmental science disciplines for tackling a societal challenge, addressing knowledge is critical.

Therefore, this paper investigates an alternative approach to improving ecodesign implementation by simultaneously addressing the knowledge to process the information in ecodesign and the implementation aspect. The objectives are to critically review earlier academic publications on Ecodesign and thereby show that an alternative approach requires more research and to obtain practitioners' views on this approach. Improved implementation of ecodesign, in general, shall result in shorter lead time and improved quality to include environmental performance, which indicates the significance of this research. The scope for this specific research from the view of engineering design excludes other fields of research at a more organizational level such as environmental management systems and green supply chain management. This paper, hence, targets ecodesign by a group of practitioners involved in the design activities of their respective manufacturing companies. In particular, this research explores the potential of an ecodesign *knowledge holder* working with a team or organization as a potentially more effective way than designers taking on the task of performing ecodesign. The following research questions (RQs) guide this paper:

- RQ1. What knowledge is necessary to effectively implement ecodesign in manufacturing companies?
- RQ2. Is a special role as ecodesign knowledge holder sensible as an alternative to improve ecodesign implementation in the future?
- RQ3. What are the concerns and opportunities from practitioners' standpoints to effectively implement ecodesign?

The following section presents the methodology followed in this research (in Section 2): based on design theory, more specifically Descriptive Study II, and transdisciplinary research, a combined systematic and narrative literature review is adopted to answer RQ1, complemented by interviews with practitioners. The results from the literature review lead the authors to hypothesize the need for an ecodesign knowledge holder, here called a “lifecycle engineer”, for an alternative to more effective ecodesign implementation as a potential answer to RQ2 (in Section3). The analysis (in Section 4) shows practitioners' concerns to effectively implement ecodesign. The proposal of a lifecycle engineer is also consulted with practitioners to answer RQ3. The discussion (in Section 5) compares the findings with previous literature and present examples from related fields of practice. Finally, the paper concludes with a brief summary and future research (in Section 6).

2. Methodology

2.1. Theories and framework used for this research

Ecodesign, according to its definition, can be regarded as a subdiscipline to be established within engineering design (e.g., Pahl and Beitz, 1988) while incorporating environmental science as needed (National Centre for Education Statistics, 2000). The process of establishing this discipline involves building a comprehensive framework to address a societal challenge and thus is a kind of transdisciplinary (TD) research (see Sakao and Brambila-Macias, 2018). Hence, this article borrows theories from engineering design and TD research (as defined by the National Research Council, 2014) to define relevant constructs as a framework to meet the mentioned objective efficiently.

A widely used research methodology in engineering design is the design research methodology (DRM) (Blessing and Chakrabarti, 2009). Since this research scrutinizes the implementation of ecodesign in industry, it is classified as a Descriptive Study II (DS-II) in the DRM. In conducting a DS-II, the relevant aspects being considered (ibid., pp. 200) are 1) need of the users, 2) conceptualization of the support and the underlying assumptions, 3) the actual support, 4) introduction, 5) impact, 6) efficiency, 7) user competencies, preferences, beliefs, interests and motivations as well as behaviour during use, and 8) organizational, technical and other contextual pre-requisites. The second and third aspects are often documented as methods in the engineering design literature. The fifth and sixth aspects may be grouped into performance for simplicity, while the first and seventh into user. In the eighth, the technical context is omitted because this research concerns generic ecodesign not focusing on any specific sectors or techniques; thus, a construct is captured as organizational context. The fourth aspect means implementation, which is the topic itself of this research, and thus not listed as a special construct. Based on the discussion above, the relevant constructs to investigate the implementation are method, performance, user, and organizational context.

For TD research, Carew and Wickson (2010, pp. 1147) suggest as a “broad consensus on the characteristics” of TD research: 1) the focus on socially relevant issues, 2) transcending and integrating disciplinary paradigms, 3) doing participatory research and 4) the search for a unity of knowledge beyond disciplines. This suggestion is acknowledged by Pohl (2011) and in line with debates on TD research in the context of environmental sustainability (Mauser

[4] Many interpretations of what a designer does can be found in Daly et al. (2012). In this paper, what Daly et al. call evidence-based decision-making (Category 1) and organized translation (Category 2) are closer to the authors' understanding. Category 1 is defined as “finding and creating alternatives, then choosing among them through evidence-based decisions that lead to determining the best solution for a specific problem”, while Category 2 means “organized translation from an idea to a plan, product, or process that works in a given situation” (pp. 199).

et al., 2013). The first three characteristics are inherent in ecodesign research or incorporated into the research presented in this paper. The fourth concerns knowledge, and needs to be captured for this research as a construct. Based on DRM and TD research, therefore, the relevant constructs for this research are method, performance, user, organizational context, and knowledge. This choice is also supported because ecodesign may be seen as a result of incorporating knowledge about the environment into engineering design. Each construct is defined in this paper more specifically as follows:

- Method: a predefined description that supports achieving a specific goal (see Andreasen et al., 2015).
- Organizational context: organizational aspects such as origin and history, ownership and control, size, charter, technology, location and dependence on other organizations (see Pugh et al., 1969) that affect the implementation of an artifact.
- Performance: an assessment of an intentional action (see Ermolayev and Matzke, 2007).
- Knowledge: understanding of the relevant causal mechanisms that generated the data and facts (see Ciesielski et al., 2017).
- User: a person who uses an artifact (own authors' definition).

2.2. Methods used in this research

2.2.1. Overview

The methods followed in this research comprised 1) a combined systematic and narrative literature review and 2) semi-structured interviews. These were performed in a sequence so that the output of the literature review was used for the semi-structured interviews. In each of these methods, content analysis was performed using a spreadsheet; see Fig. 1 for an overview of the methods used in this research.

2.2.2. Systematic and narrative literature review

A combined systematic and narrative literature review was carried out to overcome each other's drawbacks, namely, not finding all relevant results with a keywords search and a lack of traceable and systematic search. For the systematic literature review, the scientific database used was the ISI web of knowledge. This database was selected as it provides high-impact journals, which, to a certain extent, can efficiently show scientifically validated approaches for ecodesign implementation. The following keyword search was utilised (TS means topic):

(TS=("practice") OR TS=("implementation") OR TS=("industry") OR TS=("adoption") OR TS=("effective") OR TS=("success")) AND (TS=("ecodesign"))

The last search, carried out in December of 2018 for publications in the English language from 1975 to 2018, used two databases: the Science Citation Index Expanded and the Social Sciences Citation Index. Articles were screened for their relevance to ecodesign implementation through reading the titles and abstracts. Later, a narrative literature review (see Baumeister and Leary, 1997) was used to include articles that use other terms similar to ecodesign, for example, design for environment, not captured by the keyword search.

This review was performed to categorize the collected publications by using the five constructs derived in Section 2.1, thereby identifying relatively missing insights and answering RQ1 and RQ2. Answering RQ2 involves the conceptualization of the ecodesign knowledge holder. Note that this method inherently discovers no statistics of ecodesign implementation in industry but reveals the overall achievement of academic ecodesign research against the constructs that are judged essential from the existing relevant theories.

2.2.3. Semi-structured interviews

Semi-structured interviews were carried out with ten practitioners in the Swedish manufacturing industry from five different large companies from different sectors (see Table 1). The questions of the interviews concerned 1) their experience with ecodesign implementation, 2) knowledge needed for ecodesign, 3) what is needed for the users performing ecodesign, and 4) the proposed lifecycle engineer concept. The work positions of each interviewee and industry are provided in Table 1, and the participants were selected due to their experience in ecodesign. Their experience in performing ecodesign ranges from limited experience of less than two years, up to twenty years. Each of the ten interviews lasted an average of 1 h and took place between March 18th and June 11th of 2019. The interviews were voice recorded and later transcribed by one researcher and sent to each participant to validate the transcription. Afterwards, the content analysis was performed by two researchers to later compare codes and categories and reduce variability: when differences arose between the two coders, a discussion was taken to reach an agreement. The semi-structured interviews consisted of six questions and five sub-questions, which can be found in Appendix C. The semi-structured interviews were carried out with the objective to interactively explore the three RQs to derive foundations comprising qualitative insights from practitioners that could be later exploited in a large-scale study.

3. Results

3.1. Structured and narrative literature review

The structured literature review yielded 350 hits, further limited by only article publications in the English-specific databases, which resulted in 181 articles. The remaining articles were later screened for their relevance to ecodesign implementation through reading

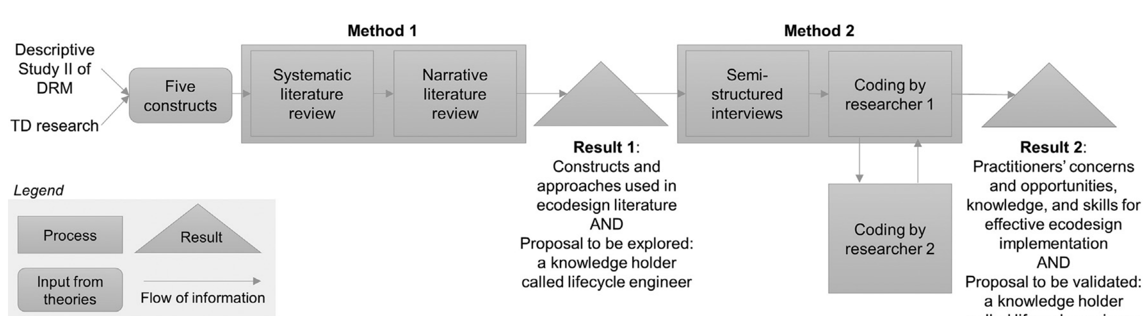

Fig. 1. Methods followed in this research.

Table 1
Practitioners interviewed.

Respondent	Company	Position/Experience	Industry sector
R1	A	Ecodesign volunteer with previous work experience of 15 years performing ecodesign as well as 20 years teaching ecodesign. Self-described as a lifecycle engineer	Electronics
R2	B	Environmental specialist with 13 years of experience in ecodesign	Transport
R3	C	Environmental product manager with 2 years of experience in ecodesign	Telecommunications
R4	C	Section manager in systems with 3 years of experience in ecodesign	Telecommunications
R5	C	Environmental product manager with 20 years of experience in ecodesign	Telecommunications
R6	C	Senior environmental expert with 9 years of experience in ecodesign.	Telecommunications
R7	C	Senior developer mechanical design with 2 years of experience in ecodesign	Telecommunications
R8	C	Materials specialist with 6 years of experience in ecodesign	Telecommunications
R9	D	Principle scientist at a corporate research facility with 8 years of experience in ecodesign	Energy
R10	E	Environmental strategist with less than 2 years of experience in ecodesign	Transport

the titles and abstracts, giving a final result of 111 journal articles. The narrative literature increased the total number of papers reviewed from 111 to 145. The possible combinations of these five constructs were obtained, namely 31 (see Appendix A). Table 2 shows the number of articles where individual constructs were found.

In Table 2, it can be observed that most literature addresses methods with 61% of the total, which corroborates the critique given to too much research effort on methods (see Section 1). On the other hand, the knowledge (16%), user (21%) and performance (21%) received the least attention, which implies the potential need of further research (see a full account in appendix A). The manner in which the constructs for ecodesign were addressed in the literature is presented and explained below.

Method is an overarching concept that includes tools, methods, guidelines, and frameworks to aid ecodesign practice. A method can have various purposes, for instance, to formulate product end-of-life strategies (Rose et al., 2002), to assess (Park et al., 2006), to provide inventive guidelines (Russo et al., 2014) and to offer generic advice (Luttropp and Lagerstedt, 2006).

Organizational context is the context that influences ecodesign taking place in an organization. The literature shows that ecodesign implementation could benefit from taking into account the organizational context (Charter, 2001; Ritzén and Lindahl, 2001) and that a softer side of ecodesign could also play a role in its effectiveness (Boks, 2006; Brones et al., 2017; Verhulst et al., 2007). Managerial practices to implement ecodesign into a design process, the environmental strategy of the organization and core values of the organization are such examples.

Performance here means the result of assessing an activity with indicators in a concerned organization, for example, CO_2 emissions for a specific activity and the lead time of an ecodesign project (Rodrigues et al., 2016). Performance can then show how well a specific strategy is performing (Cerdan et al., 2009) or can serve as a basis for comparison (Short et al., 2012). *Performance* is highly relevant in an industrial setting, because, for instance, it can be used for assessment of how well products from an organization are complying with environmental legislation (see Pigosso et al., 2016).

User refers to practitioners in an organization that use a defined ecodesign method or use the result from the method usage. The *user* has an impact on the output of the method usage because of their different backgrounds through education and training as well as different incentives for their work. The literature informs the user's importance for ecodesign methods to be used efficiently and effectively (e.g., Lindahl, 2006; Birch et al., 2012).

Knowledge provides an answer to RQ1. Schöggl et al. (2017) state that designers often struggle with finding the necessary data and information to for example assess recycling options or emission impacts while Bey et al. (2013) and Dekoninck et al. (2016) argue that expert knowledge is often needed to support ecodesign activities. As reported by Dekoninck et al. (2016), Millet et al. (2007) suggest that design teams can acquire the necessary environmental knowledge through: a) a new expert, b) methods or c) an existing team member developing the necessary expertise. Therefore, the *knowledge* construct here refers to a) a knowledge holder as proposed here, b) knowing what a given ecodesign method is and how to use it correctly, for example, background knowledge to understand a certain method (see Vallet et al., 2013) and c) data and information, as part of knowledge, which may originate from different stakeholders such as product users (Aschehoug et al., 2012), intermediaries (Hjelm and Lindahl, 2016; Küçüksayraç et al., 2017), and university education (Verhulst and van Doorsselaer, 2015).

Table 3 provides a more detailed picture than found in Table 2 of the past research with RQ2 in mind by showing the combinations of the constructs, including knowledge (K) and user (U). No paper focused on K and U (ID1 in Table 3). IDs 5 and 8 indicate that some literature touched upon K and U simultaneously, however, they addressed other constructs also, meaning the analysis pertaining to K and U can be deeper. RQ2 is answered by suggesting that (K) and (U) in combination have been less researched and provides the preamble to hypothesize of a knowledge holder has the potential to more effectively implement ecodesign. Fig. 2 shows the progression of the five constructs over time based on the 145 articles reviewed. From Fig. 2, the knowledge (K) construct has had a more gradual increase (its slope is 0.076) in comparison to the other four constructs (the slopes of M,C,P, and U are 0.32, 0.29, 0.23, and 0.17,

Table 2
Frequencies of the constructs addressed in the body of literature on Ecodesign.

Construct	Count in all articles	Frequency (%)
Method (M)	89	61
Organizational Context (C)	50	34
Performance (P)	31	21
User (U)	31	21
Knowledge(K)	23	16

Note: The population is 145. One article may address multiple constructs.

Table 3
Constructs K–U and their combinations.

ID	K	M	C	P	U	Count in all articles
1	X				X	0
2	X	X			X	0
3	X		X		X	0
4	X			X	X	0
5	X	X	X		X	2
6	X	X		X	X	0
7	X		X	X	X	0
8	X	X	X	X	X	5

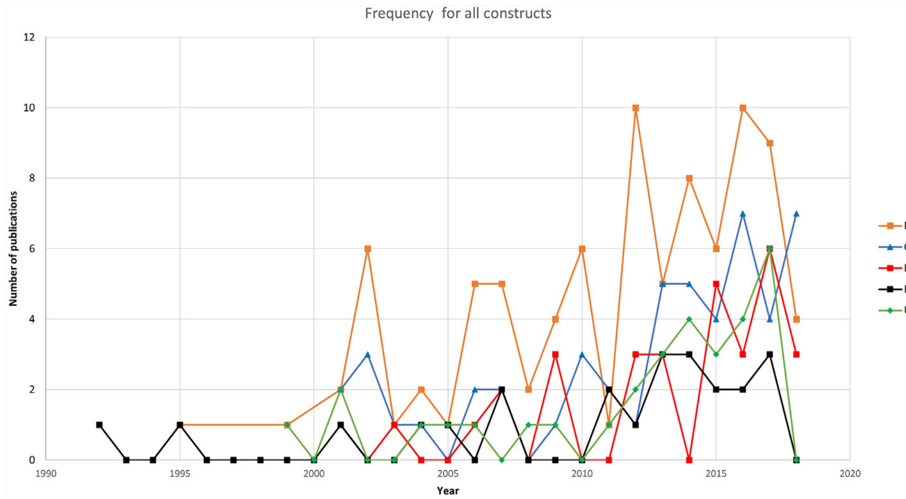

Fig. 2. Frequency of constructs over time.

respectively), see Appendix B. This is surprising since (K) has been pointed out as a challenge for ecodesign implementation (see Dekoninck et al., 2016), and yet the literature on (K) seems limited.

3.2. Proposal of a knowledge holder

Based on the literature addressing the knowledge or user construct, the concept for the ecodesign knowledge holder is described below. The knowledge holder is termed as a lifecycle engineer, first because an emphasis on a lifecycle approach has been the focus of the field from the beginning (see Ceschin and Gaziulusoy, 2016) and second because it better expresses how such an engineer is expected to address problems in a lifecycle perspective (see Keoleian and Menerey, 1994). The description builds especially on the authors' reflections as well as Daly et al.'s (2012) work and the definition of lifecycle engineering in the CIRP encyclopedia by Laperrière and Reinhart (2014) . With the vision of a more sustainable future, it seems appropriate to provide a mission for and function of a lifecycle engineer.

The mission of a lifecycle engineer is *to anticipate, prevent and make evidence-based decisions to determine the best solution for specific environmental challenges and add knowledge to a team or organization in the development process*.

The function of a lifecycle engineer is *to gather information; identify, quantify and prioritize environmental impacts for relevant activities from a systems perspective; and communicate with the design team or organization possible countermeasures for efficient and effective use of resources in the entire lifecycle in order to optimize it and minimize waste and pollution*.

4. Analysis of the semi-structured interviews

4.1. Concerns and opportunities when implementing ecodesign

After reflecting on the constructs and approaches, practitioners argued the following as relevant in their practice, though not necessarily knowledge, categorised into *goals, time, requirements, prioritization, and process*.

Companies aim to make a profit and, in most cases, have specific sales or revenue goals that will drive the rest of their operations; *goals*, hence, are of extreme importance. For example, in the telecom and transport sectors, there has been a goal for several years to lower the energy use of products to remain competitive. This, in turn, has resulted in the application of ecodesign practices, for example, using less materials, as a consequence or enabler rather than the main reason for performing ecodesign.

The *time* dimension was mentioned in different ways as needed to implement ecodesign. First, time-to-market was seen as an obstacle to implement ecodesign thoroughly. Designers are under tremendous time pressure, and if including environmental aspects is not deemed essential for the design, it would be much less likely that these aspects are included. Second, it was suggested that it takes time to develop a tool useful for several actors, and implementing a tool can take several months, in some cases two to three years for larger business units, since companies run pilot studies to test how a tool is working. Finally, it was mentioned that change takes time, and ecodesign changes resulting in modifications in a product are usually done in small steps to avoid mistakes in, for example, loss of function or higher costs for the customers.

Requirements were another important issue raised. Requirements can be understood not only as customer requirements needed for the design but also for the company itself, and those coming from legislation, namely, "why are we doing this?" If customer requirements or legislation include environmental aspects, then these will be considered, and alternatively, if changes in the design will lead to an increase in profitability, then there will be a reason for addressing them. This implies that ecodesign requirements need to make business sense. Otherwise – as was previously mentioned – it will be much more challenging to include environmental aspects; they need to be supported by business reasons.

Related to requirements is the need for *prioritization*. As was mentioned during the interviews, design, in general, is about tradeoffs, and hence proponents of ecodesign need to address the prioritization of which environmental aspects are the most important. One practitioner (R1) mentioned that design meetings revolve around the requirements for the product, and if the environmental requirements are not included early on, they will not be a part of the final specifications.

During the interviews, it was mentioned that *processes* in organizations, such as gate processes for design and development, are important to consider. A process will also be product-dependent, and this process-product duality can then determine the use of methods and tools, when to introduce them and their benefits for different stakeholders. It was mentioned that some conflicts might also arise from different departments prioritizing their specific requirements and processes.

4.2. Knowledge for ecodesign

The analysis from the practitioners' answers resulted in five categories: *lifecycle analysis, materials and their selection, energy efficiency, legislation, and management*.

Lifecycle analysis is often operationalized through lifecycle assessment (LCA), which was mentioned as the method that most companies use to address environmental concerns. Knowledge of how to carry out lifecycle analysis is needed. LCA is also used by practitioners to, for example, provide specific guidelines to designers. It was suggested that knowing the right tools to use is also important. Practitioner R2 mentioned that "knowledge from life cycle assessment, what is important, and knowledge in design for recycling, knowledge about the products, and knowledge about technology" are all important.

For most companies, *materials and their selection* are of great importance, and for some, a default or self-evident type of knowledge. Some companies look to replace materials to comply with regulations but also to reduce costs. Material declarations also make part of the knowledge needed for ecodesign. In this respect, one practitioner (R5) stated that "materials knowledge can be very specific. So, in our case, we have some specialists that have chemical knowledge, our materials experts that are supporting mechanical designers and so on". Practitioner R1 also stated that previously, in the environmental department, there were two plastic experts to deal specifically with additives, recyclability of plastic and use of recycled plastic and that "you cannot require such specific knowledge from a designer, not even from an overall lifecycle engineer".

Energy efficiency was a topic to which companies have previously dedicated much effort. This was similar for all the companies, as they belong to the energy, telecommunications, and transport sectors. Energy efficiency makes part of their competitive advantage and what they offer to their customers; hence, specialized knowledge in energy is in demand, and some companies have energy experts.

Legislation, covered in the construct of performance, was very important for most practitioners and considered one of the main ecodesign drivers. A practitioner in the telecom sector dedicates most of their time to ensuring compliance with legislation for materials to be phased out. One practitioner (R9) stated the following regarding legislation: "… due to increased legislation, there are more and more materials that cannot be used in our products. We need to work proactively, because for us sometimes it takes a very long time to find a new material". Another practitioner (R6) stated that legislation should not be coupled with the performance construct and that it should stand on its own to highlight its importance, suggesting, "I think [what] we are seeing more and more are directives, laws, legal requirements, these actually have the strongest impact on ecodesign".

Management was also pointed out as needed for effective ecodesign implementation. Practitioner R1 emphasised this area of knowledge since support for ecodesign is implemented in many cases through the following: action plans, environmental roadmaps for the organization, support for environmental communication and the environment as part of remuneration schemes. It was mentioned that in association with knowledge, experience in the organization is also required in order to build trust.

4.3. Skills when implementing ecodesign

After the analysis of interviews, skills in association with knowledge were also identified as important for implementing ecodesign; these were categorised as *communication, systems* and *lifecycle thinking*.

In several of the interviews, *communication* was a recurrent topic. Communication is needed to achieve good ecodesign. This was related to communicating the need for using a specific tool, the outcome of the tool and how to implement it. It was also suggested that it is important to communicate with designers and suppliers about what is needed from them. A "translator" was another name given to what is needed in ecodesign to better communicate across different departments and communicate the value for the business in performing ecodesign. It was suggested that many employees would not be familiar with LCA, certain emissions or terms. More specifically, a primary concern is, "why are we doing this"? These methods, terms and concepts need to be translated into common engineering language, for example, to lower kW or reduce kg so that it makes sense to others and so designers can trust and feel comfortable with changes to be made.

Systems and lifecycle thinking were stressed in several of the interviews. There is a need to have the whole picture of the impact on the environment from products and the effects that changes on them will have along the lifecycle. A practitioner stated that this was needed to avoid sub-optimization as well as to analyze trade-offs. It was suggested that changes in one part of the product would impact other characteristics, and it is important to quantify and visualize it. An example was given by Practitioner R10 suggesting that replacing aluminium or steel for carbon fibre could first look like a good option since it reduces weight and could decrease energy use; however, the recycling of such material is rather difficult, which presents an important trade-off in which more knowledge is hence necessary to make the right decision.

4.4. Practitioners' views on the proposed lifecycle engineer

Most practitioners − eight out of the ten interviewed − agreed that a lifecycle engineer could be useful. In some cases, practitioners suggested that such a position was already in place and that they would have seen themselves as one. For example, Practitioner R1 self-described after the interview as a lifecycle engineer. In other cases, practitioners saw it as a needed function that could contribute to the design team, while in other instances, they saw it as a position that could work in the near future. The advantages mentioned were having more focus in ecodesign, the possibility of looking deeper into environmental issues, the availability of information, and having someone to drive change. Moreover, one practitioner (R8) suggested that rather than a person, it could be a support function made of a team of ecodesign experts that would work as a cross-functional unit to support designers. The potential disadvantages mentioned were a lack of business value for the company, if the position is cross-functional, being part of different departments and not having a "home", and difficulties for small companies in hiring such a person. It was suggested that in smaller companies, in general, one person already has many roles.

5. Discussion

5.1. Synthesis of the lifecycle engineer

Facing the current lack of prevalent implementation of ecodesign in industry and the present trends and challenges of design practice in general, the newly developed concept, the lifecycle engineer, was proposed through the literature analysis as an alternative for a better solution; see the mission and function in Section 3.2. The consultation of this proposal with the practitioners in industry has confirmed the potential and feasibility of the lifecycle engineer to improve ecodesign implementation, at least in large organizations (see Section 4.4). The knowledge that the lifecycle engineer is expected to add in the development process (see the mission stated in Section 3.2) should cover lifecycle analysis, materials and their selection, energy efficiency and legislation, according to the interviewed practitioners. Not only knowledge but also skills are highlighted as important by the practitioners for the lifecycle engineer to possess, and communication as well as systems and lifecycle thinking.

5.2. Scientific contributions

The first contribution is the advancement of the insights for implementing ecodesign in an organization thanks not only to a thorough review of the literature but also consultation with industry. The five constructs derived from engineering design and TD research (see Section 2.1) were found to feature and categorize various ways of ecodesign implementation and can be used for further research. As was shown, knowledge to effectively implement ecodesign is under-researched and could provide further details crucial to advancing ecodesign and its implementation in industry. Similar to Johansson (2002), Dekoninck et al. (2016) previously highlighted similar concerns, namely, strategy, tools, collaboration, management, and knowledge, pointing out challenges in each of these categories. Similarly, Rossi et al. (2016) previously addressed the classification of ecodesign methods along with barriers for implementation such as knowledge, time, a large number of tools and over-formalization of methods. However, the research presented here also provides further undeveloped areas of research, such as performance (P) and the user (U) of the support, which received little attention, by combining the different constructs derived from engineering design and TD research (see Section 2 and Appendix A).

Second, the practitioners' concerns obtained from the industrial consultation (see Section 4) provide a more detailed account of concerns and opportunities for ecodesign from the perspective of knowledge, answering RQ3. Some of these findings overlap with previous academic research. For example, Mathieux et al. (2001) provided five principles for ecodesign implementation, namely: lifecycle thinking, ecodesign process, tools, and methods, ecodesign strategies and dialogue, and partnership. The difference is that their findings seem to focus more on methods, organizational concerns, and skills. Here, a more detailed description of what a user needs to know to effectively carry out ecodesign is also provided, answering RQ1.

The third and most important contribution is the proposal of the newly developed concept, the lifecycle engineer, after finding little research devoted to the knowledge and user constructs. This proposal aims to realize the knowledge and the user (out of the five constructs) in one role, and thereby is regarded to provide a potential solution for the present design practice in industry to improve ecodesign implementation. This concept was perceived by the practitioners to have the potential for improved implementation of ecodesign. This means that the lifecycle engineer concept makes sense as a potential solution and answers RQ2. Previous literature is acknowledged pointing out the need for the role of environmental specialists in ecodesign (see Bonou et al., 2016; Dekoninck et al., 2016) but without more details of their necessary knowledge and skills. This article provides an account of what knowledge and skills are necessary for such a key role. Moreover, design concerning environmental sustainability has been expanding its scope according to societal needs, such as the transition to a circular economy.[5] This trend with the need for new capabilities (Section 1) will further increase the relevance of investigating roles and knowledge expected on various practitioners involved in design for sustainability.

As the last contribution, reflecting on DRM, which was adopted as a framework for this research, this paper implies two issues. First, the knowledge construct was shown relevant in ecodesign, although it is not outspoken as an important aspect to be considered in DS-II of DRM. This issue has begun to gain attention in engineering design in general (see a study in the embodiment design phase in Reimlinger et al., 2020) as well as in multidisciplinary engineering design (see a study on collaboration with data analysts in Hiruta et al., 2019). Second, in relation to knowledge, skills for, for example, communication were also a new relevant aspect with reference to DS-II of DRM. These issues are considered a natural consequence of expanding design in the context of transdisciplinarity, that is, the increasing number of disciplines addressed and the need for communication with various groups of people. This possible need to consider knowledge and skills in addition to improving engineering design practice in general with an observation of the growing gap of knowledge and skills (related to lifecycle engineering and communication) between education and labour market in the field of industrial design (Alonso-García et al., 2020) might indicate a common underlying trend in our societies.

5.3. Comparison with other subjects

The "how" and "who" of implementation are also found in more mature subjects of practice. Take, for example, Six Sigma in quality management (Zu et al., 2008); its effective implementation has been discussed substantially (Blakeslee Jr, 1999; Henderson and Evans, 2000). What is crucial for the effective implementation of Six Sigma is reported to be management involvement, commitment, and training, among other characteristics (ibid). Communicating how to implement it is indeed an imperative (Antony and Banuelas, 2002), a part of success factors identified (Ismyrlis and Moschidis, 2013) and which can have a positive effect on corporate competitiveness (Lee and Choi, 2006). In Six Sigma, a standard five-stage improvement process to define, measure, analyze, improve and control is used for its implementation (Snee, 2004). To successfully carry out this process, knowledge in statistics, among other things, is needed (Hoerl, 2001). Interestingly, the knowledge and the user are addressed in one (see Anand et al., 2010; Hoerl, 2001; Ingle and Roe, 2001), which is represented by different levels of knowledge of an individual practitioner: green, black and master black belts.

Another example is lean manufacturing, which is based on the key principles of identification of value, elimination of waste and generation of smooth flow (Womack et al., 1990), along with specific tools, for example, seven value stream mapping tools and seven waste tools (Hines and Rich, 1997). Similar to Six Sigma, it has been suggested that lean manufacturing requires effective communication for successful implementation (Cassell et al., 2006; Mostafa et al., 2013; Puvanasvaran et al., 2009; Scherrer-Rathje et al., 2009).

In comparison, ecodesign lacks discussions on its different levels of expertise similar to a green, black or master black belt. This fact may be supported by the lack of addressing the knowledge and the use in one as it has been done in lean manufacturing and Six Sigma (e.g., ISO:18404, 2015). These other fields of practice have benefited from addressing, for example, the necessary knowledge that a user needs to possess for effective implementation. Ecodesign implementation could benefit from further enhancing its implementation with practical findings from related subjects.

Additionally, the results of this research for the construct knowledge and user can be an input for developing a precise

[5] Ceschin and Gaziulusoy (2016) synthesized the expansion of the scope from insular to systemic as well as from technology to people.

Ecodesign Body of Knowledge (BoK). Existing BoKs in more established disciplines in for example, Environmental Engineering (AAEE, 2009) and Industrial Engineering (see IISE, 2019), could be used as templates to further advance the knowledge and competencies of a lifecycle engineer. It can also provide the depth to which knowledge in a specific topic is required, as R1 suggested, for knowledge of materials and their selection “you cannot require such specific knowledge from a designer not even from an overall lifecycle engineer” Various educational institutions already include topics relevant for Ecodesign in engineering programs (see De los Rios and Charnley, 2017; Verhulst and van Doorsselaer, 2015) and could further exploit the findings of this paper to further develop the Ecodesign BoK and address the necessary changes in manufacturing companies towards a more sustainable future.

5.4. Limitation of the study

This paper presented one view in a multitude of research that concerns ecodesign implementation. Also, the interviews were based on a specific country (Sweden) that is recognised as advanced with regard to environmental aspects, focusing on large companies and in a limited number of sectors. Thus, the lifecycle engineer concept was explored, hence waiting for its wider application and validation for generalization in more countries, types of organizations and sectors. Research in the form of surveys and questionnaires will enrich and consolidate the concept as well as enhance the validity of the findings. However, the paper provided the first steps towards the establishment of the Ecodesign BoK.

6. Conclusions and future research

The literature suggests that answers to the questions of “why”, “what” and “how” with regard to ecodesign have been previously addressed. Enablers, barriers, drivers, and available methods are examples of what is often encountered in the literature to answer such questions. However, the lack of ecodesign implementation remains an issue. What has been previously lacking is to go beyond pointing out the barriers and drivers and address in more detail the questions of “how” and “who” in combination concerning ecodesign in the industrial context.

A set of ecodesign constructs and approaches for effective implementation were suggested based on theories of engineering design and transdisciplinary research. The results from the literature review showed a gap needing further exploration, namely the constructs of knowledge and user as currently needing further research. In order to address this gap, the authors proposed a knowledge holder to more effectively implement ecodesign. This knowledge holder was named lifecycle engineer. Constructs, approaches and the proposed lifecycle engineer were then used to carry out semi-structured interviews with practitioners in industry. After these interviews were carried out, specific practitioners' concerns, knowledge and skills were obtained and categorised to effectively implement ecodesign. The answers to the research questions can be summarized as follows: RQ1 What knowledge is necessary to effectively implement ecodesign in manufacturing companies? The specific answer based on this research is *lifecycle analysis, materials and their selection, energy efficiency, legislation, and management*. RQ2. Is a special role as ecodesign knowledge holder sensible as an alternative to improve ecodesign implementation in the future? The lifecycle engineer concept was scarcely researched but welcomed by most practitioners; however, conclusive evidence can be obtained in further research. RQ3. What are the concerns and opportunities from practitioners' standpoints to effectively implement ecodesign? Practitioners' concerns, which can be seen as areas of opportunity, were classified as *goals, time, requirements, prioritization, and process* and necessary skills as: *communication, systems and lifecycle thinking*.

Further research could expand the sectors and countries to test the validity of the findings in different contexts. This could be carried out in the form of surveys and questionnaires to cover a larger number of respondents. Moreover, the research presented here also provided further undeveloped areas of research by combining the different constructs found in the literature (see Section 3 and Appendix A). Finally, a knowledge holder also has the potential to support implementation in other fields of research similar to ecodesign, for example, design for sustainability and the circular economy, and in doing so, contribute to a more sustainable future.

CRediT authorship contribution statement

Sergio A. Brambila-Macias: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Tomohiko Sakao:** Methodology, Resources, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by the Mistra REES (Resource-Efficient and Effective Solutions) program, funded by Mistra (the Swedish Foundation for Strategic Environmental Research) (DIA 2014/16). Special thanks to Don Huisingh for his comments in an earlier version of this paper, to Mattias Lindahl for later suggestions and to Raphael Wasserbaur for support in the coding and further comments on the categories found in the transcribed interviews.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123520.

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