ANALYSIS AND EVALUATION IN THE EARLY STAGES OF DESIGNING RESOURCE EFFICIENT OFFERINGS: A COMPARISON AMONG LARGE COMPANIES AND SMALL AND MEDIUM ENTERPRISES

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ABSTRACT

In Europe there is a common vision to transform the economy into a sustainable one by 2050 which among other changes, calls for companies to address their offerings in a more resource-efficient manner. Therefore, efforts to provide design support namely, methods, guidelines and tools to specifically address natural resources and impact of products and services have been increasing. Moreover, companies of all sizes should integrate environmental concerns as early as possible to select profitable and environmentally sound offerings. However, knowledge of the analysis and evaluation of resource-efficient offerings seems currently insufficient especially with regards to similarities and differences among different company sizes. In this paper, the study of eight case companies: 3 large companies and 5 SMEs, shows how industry addresses the analysis and evaluation of their offerings. Commonalities among SMEs and large companies include decisions made by strategic or managerial boards, the use of mock-ups and project management skills, among others. These findings could help academics in providing relevant, useful and usable support to industry.

Keywords: Evaluation, Ecodesign, Decision making

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1 INTRODUCTION

The United Nations' earth summit conference held in Rio de Janerio, Brazil, in 1992 provided the Agenda 21 action plan, which reflected among other aspects the importance of the efficient use of natural resources with the aim of minimizing resource depletion and reducing pollution (Sitarz, 1993). In the business arena, The World Business Council for Sustainable Development (WBCSD) originally formed in 1991 has continuously worked with business practices under the term eco-efficiency highlighting resource productivity to obtain more from less energy and raw material input and increasing customer value while reducing environmental impacts (DeSimone and Popoff, 2000) Moreover, Resource-efficient Europe is a flagship initiative of the Europe 2020 Strategy promoting the decoupling of economic growth from resource use (Kaźmierczyk *et al*., 2016).While many definitions of the concept resource efficiency exist (Kaźmierczyk *et al*., 2011), it can be defined as "using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment… create more with less and to deliver greater value with less input" (European Commission, 2017). Furthermore, in the past access to cheap resources could provide a competitive advantage, however today this is more determined by how a company uses its resources where competitiveness and environmental soundness are not mutually exclusive (Charles Jr *et al*., 2017).

Moreover, Design has been highlighted to contribute to competitive advantage (Sisodia, 1992). Indeed, Wallace and Burgess (1995) suggest that the British Standard 7000 "Guide to Managing Product Design" clearly states that one of the aims of engineering design is securing competitive advantage. The importance of design in business is also reflected in related design fields, namely design management and design thinking (Cooper *et al*., 2009). Additionally, Design or in this paper Designing to highlight it as a social process with multiple stakeholders, iterations and objectives (see Bucciarelli, 1988) is considered by many as a decision-making process (Lewis *et al*., 2006) where concept selection is often considered part of the most crucial stages in the engineering design process (Ullman, 2002) which includes design evaluation activities e.g., analysis and evaluation (Sim and Duffy, 2003). Howard *et al*. (2008) compare engineering design processes across the literature while suggesting that these namely cover the following phases: establishing a need, analysis of task, conceptual design, the embodiment of design, detailed design and the implementation phase. In this paper early stages of designing cover mainly the first three phases: establishing a need, analysis of task and conceptual design. Moreover, Analysis and Evaluation are key activities in designing according to Gero (1990). In terms of size of companies, the European Commission (2015) differentiates SMEs as those with less than 250 employees not exceeding EUR 50 million in annual turnover and/or an annual balance sheet not exceeding EUR 43 million. While differences among large and small companies exist, there are also similarities which are often overlooked. For instance, the necessity to innovate exists in both types of companies. Also, how in practice environmental aspects influence decision making and hence the final offering remains unclear. For these reasons, this research paper has the aim to describe current practices in industry regarding support, e.g., tools, methods and guidelines used for the analysis and evaluation of resource-efficient offerings and provide similarities and differences among large companies and SMEs. This research was carried out in the Swedish manufacturing sector and the following research questions are addressed in this paper:

- How do manufacturing companies analyse and evaluate resource-efficient offerings in the early stages of designing?
- What do manufacturing companies need for the analysis and evaluation of resource-efficient offerings in the early stages of designing?
- What are the differences and similarities between large companies and small and medium enterprises in the analysis and evaluation of resource efficient offerings?

The following section 2 presents past research related to resource-efficient support for analysis and evaluation in early stages of designing. Next, Section 3 provides the reader with a broad picture of the method followed in this research. Section 4 then shows results from the interviews carried out with manufacturing companies, and Section 5 is dedicated to a short discussion of the results. Finally, Section 6 presents conclusions and future research.

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2 LITERATURE REVIEW

For the purpose of this paper, Analysis is understood as including problem-solving tools or methods and skills in solving mathematical equations, modelling and simulation. In contrast, Evaluation is seen as support that includes knowledge, experience and decision makers' preferences.

2.1 Support for analysis

An early review of analytical environmental support is provided by Wrisberg *et al*. (2002) as part of the European Environment and Climate Program called CHAINET which was carried out between 1997 and 1999. Their review categorizes support into: analytical, which provide consequences of a choice; procedural, to reach a decision; and technical, which support all previous tools. Some of the support analyzed under CHAINET includes cost benefit analysis (CBA), cost effectiveness analysis (CEA), material flow accounting (MFA), life cycle assessment (LCA), environmental risk assessment (ERA) and environmental input output analysis (env. IOA). All these often need extensive information to quantify environmental impacts. Furthermore, in engineering projects, one of the earliest methods - which was later adapted to environmental costs – is suggested to be life cycle costing (LCC) (Gluch and Baumann, 2004). In relation to design, Bieda (1992) contribute with an LCC methodology that presents quantitative estimates for design feasibility for the early phase of design. It focuses on warranties as well as the impact of changes on reliability, repair costs and purchase costs. Bieda (1992) suggests that LCC helps to promote teamwork between the engineering and business community. Other methods under the category of Analysis relate to the fulfilment of multiple criteria. These are usually found in decision-making literature. Decision analysis methods can be categorised into single objective decision making (SODM), subdivided into decision trees and influence diagrams and decision-support systems (DSS) and those that fall under multi-criteria decision making (MCDM). MCDM can be divided into multi-attribute decision making, or MADM, and multi-objective decision making, or MODM (Zhou *et al*., 2006). Zavadskas *et al*. (2014) suggest that MODM methods are used in design with problems where alternatives are non-predetermined, and the aim is to choose the best or optimal alternative according to well defined constraints and quantifiable objectives. Thies *et al*. (2018) suggest that MODM is mainly concerned with decision-making problems where multiple conflicting objectives must be considered and that unlike MADM, MODM deals with design problems and not with choice problems. According to Thies *et al*.'s (2018) review on sustainability assessment of products using MODM methods, included are stochastic optimization, fuzzy logic and genetic algorithm.

2.2 Support for evaluation

Bovea and Pérez-Belis (2012) categorize qualitative, semi-quantitative and quantitative support. Support categorized as qualitative and semi-quantitative is more in line with the description of evaluation in this paper. Qualitative support includes checklists used by companies such as AT&T, Volvo and Kodak as a series of questions to help designers work in a systematic manner. Other support includes, The Matrix Element Checklist for ERP by Graedel and Allenby (1996), a combination of questions to reduce subjectivity. Ten golden rules by Luttropp and Lagerstedt (2006); a series of guidelines to facilitate the integration of environmental aspects into the product development process, and the Materials, Energy, Toxic emissions (MET) matrix by Brezet and Van Hemel (1997) to identify the severity of environmental impacts in a qualitative manner. Support which can be categorized as semi-quantitative include Environmental Effect Analysis (EEA) by Lindahl (2001), which is turn based on Failure Mode Effect Analysis (FMEA), to identify and list activities with the most significant environmental impacts and carry out actions to reduce or eliminate these impacts. Quality Function Deployment for Environment (QFDE) by Masui *et al*. (2002) includes environmental aspects as quality requirements seen in the traditional voice of the customer. Additionally, support from the discipline of decision analysis can also be classified as belonging to support for evaluation. Zavadskas *et al*. (2014) explain that MADM methods deal more with rational choice theories that assume individuals must anticipate outcomes of different alternatives and choose the best option for them. MADM, the authors suggest, are related to the expected utility model. Thies *et al*. (2018) suggest that most frequent MADM methods for sustainability assessment of products are the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization Method for

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Enrichment Evaluation (PROMETHEE), Elimination Et Choix Traduisant la Réalité (ELECTRE), Simple Additive Weighting (SAW), and Multi-Attribute Value/Utility Theory (MAVT/MAUT).

Finally, there has been criticism for support that does not include social aspects of sustainability (Byggeth *et al*., 2007). For example, Schöggl *et al*. (2017) point out that ecodesign or design for environment disregard the social dimension of sustainability. They instead provide a new checklist for Sustainable Product Development (CSPD) applied in the automotive industry to stimulate collaboration and information exchange within and between organizations. Moreover, Ceschin and Gaziulusoy (2016) suggest that there is an on-going progression which started from product focus seen in the field of ecodesign to integrating services and now an effort to address sustainable system design.

2.3 Large companies and SMEs

Research in the early stages of designing carried out at large companies includes that of Kihlander (2011) and Lopez-Mesa and Bylund (2011), who studied Volvo Var Corporation and conclude that designers make little use of formal or normative decision making support during concept selection and minimal use of structured methods, respectively. Lopez-Mesa and Bylund (2011) suggest that designers prefer guidelines or methods that address their needs. Moreover, through their publication "Eco-efficiency: the business link to sustainable development" the WBCSD showed how large companies have made use of tools, guidelines and principles to realize offerings that are more resource efficient. The successful use of tools is seen in large companies such as Dow Chemical and its eco-compass method, BASF and its eco-efficiency analysis and Philips' ecodesign practices, among other large companies' examples (DeSimone & Popoff, 2000).

Publications that address SMEs describe barriers and drivers to engage in for example ecodesign initiatives (van Hemel and Cramer, 2002) or advantages and disadvantages of eco-efficiency (Fernández-Viñé *et al*., 2010). Findings suggest SMEs are driven by cost reductions or avoiding non-compliance sanctions rather than using eco-efficiency practices due to customers' demands. Ardente *et al*. (2006) argue that SMEs generally struggle with complex information coming from different partners in the supply chain and are unable to develop improvements based on the environmental profile of products.

In general, large companies and SMEs will present opposite characteristics. Nicholas *et al*. (2011) suggest that large companies usually are more hierarchical with limited top management visibility, better access to human and financial resources, higher resistance to change and less encouragement for individual creativeness. SMEs are characterized by a flatter structure, high top management visibility, limited access to human and financial resources, negligible resistance to change and higher degrees of individual creativeness. It is then not surprising that large companies and SMEs are often studied separately. However, some similarities could include: environmental innovations (Chen *et al*., 2006) compliance with environmental regulations (Zailani *et al*., 2015) and desire to increase market share (Cai and Li, 2018) among others. These similarities should not be neglected if researchers of design aim at providing support that is relevant, useful and usable in industrial settings.

3 METHOD

Cross (2006) suggests that research about design can be carried out through interviews, observations, case studies, protocol studies, reflection and theorizing, and simulation trials. In this research, interviews with practitioners were utilized as they were deemed most appropriate. It allowed participants to discuss the general design process, and the analysis and evaluation of their offerings as well as other aspects relevant to design in their organizations. Other methods, such as observations and simulation trials did not fit the purpose of the research since they could potentially interrupt on-going work or raise issues pertaining confidentiality. The method was also chosen due to availability of respondents and their relevant experience or direct participation in the design process. Blessing and Chakrabarti (2009) suggest that interviews are a retrospective data-collection method which is common in industrial settings. Difficulties in carrying out interviews include the rapport or social interaction between interviewer and respondent (DiCicco-Bloom and Crabtree, 2006), leading

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respondents to answer in a certain way or respondents answering what the interviewer wants to hear (Robson, 2011).

3.1 Details of interviews and their analysis

Interviews were semi-structured to allow for interviewers and respondents to build upon important points while keeping an agenda throughout the interview. Interviews lasted from 60-70 minutes and were all sound recorded and most also video recorded to capture any drawings made on paper and corresponding explanations. Interview questions touched upon other topics than analysis and evaluation, for example on gathering requirements. For this paper those related to analysis and evaluation are provided. Questions also involved asking what would be needed that was not currently in place for more resource-efficient offerings. For instance, who should be involved in the design process? The interviews were carried out between April and June of 2016 with follow up meetings between February and April of 2017. These meetings were used to provide a short summary, validate what was discussed during the interviews and highlight possible points that respondents seemed relevant to add. These meetings were documented with meeting minutes.

3.2 Analysis of interviews

Interviews were analysed through a template divided into pre-defined sections corresponding to questions asked during the interviews to categorize relevant information from the answers given by interviewees and find commonalities and differences among large companies and SMEs. The analysis was carried out by dividing the interview answers from the 8 different companies among 3 different researchers. In order to reduce possible bias and validate the results, in addition to the template to categorize the different answers, the authors compared what was recorded in the interviews with short summaries of the interviews and meeting minutes verified by all companies involved. Additionally, during interviews, some practitioners drew on paper the process to help identify working practices and the use of support. This triangulation allowed for a more thorough review of practitioners' claims and their validation.

4 RESULTS

A total number of 24 interviews were carried out in 8 different companies. The results show high level summaries as it attempts to provide main similarities and differences, further details are provided in section 5. Table 1 presents the size of the companies, their industry, the number of interviews and type of design process. Table 2 and Table 3 show a comparison of the aggregate and most frequent answers from the interviewees, summaries and meeting minutes. Table 2 shows the current status and Table 3 the needs of companies.

Table 1. Participating companies, industries, interviews and early design process

Company (size)	Industry	# intv	Process for early stages
A (large)	Health care products	3	Project management process with check points
B (large)	Heavy duty and off-road vehicles	5	Stage gate and V model
C (large)	Transportation	4	Stage gate and V model
D (SME)	Floor grinding and cleaning	5	Stage gate process
E (SME)	Remanufacturing of electronics	2	No formal product development process
F (SME)	Sustainable materials for the construction and paper mill industries	3	Semi-formal process
G (SME)	Facade cleaning	1	No formal product development process

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H (SME)	Sales and installation services of engineering equipment	1	No formal product development process

Table 2. Current status large companies vs SMEs

Questions and answers for current status for large companies	*Questions and answers for current status for SMEs*
Who is involved in the process? Customers, buyers, production managers, project owners, R&D managers, quality managers.	*Who is involved in the process?* Business owner, project leaders, sales personnel.
Who makes decisions? R&D manager, project owners.	*Who makes decisions?* Business owner, designers, project leaders, product owners, strategy group, division managers.
How are environmental factors addressed? Through checklists and environmental impact assessments, black lists and internal indicators.	*How are environmental factors addressed?* Circular thinking, material recycling and energy use.
How are economic factors addressed? Feasibility studies, predefined budget, calculation spreadsheets.	*How are economic factors addressed?* The main aspect is if an offering is profitable.
How are uncertainties addressed? Pre-studies, discussions with suppliers, lab tests, early tests of products through indicators that need to be fulfilled, test driving, risk analysis, risk registers, mock-ups and pilot studies.	*How are uncertainties addressed?* Test over long periods, production 0, Practical tests through mock-ups, Gut feeling, attending fairs and follow latest developments through news outlets, in many cases by the owner(s) of the company.
What support is used? LCC, LCA, FMEA, QFD, A3 reports, Lab tests, ISO 14001, life cycle management, pilot studies, virtual testing, ISO test methods, design for assembly and eco-labels like Swan.	*What support is used?* Design for disassembly, FMEA, risk analysis, ISO 14001 and A3 reports.
What training is given? Project management and leadership.	*What training is given?* Training to customers on how to use the product.

Table 3. Needs of large companies vs SMEs

Questions and answers for needs for large companies	*Questions and answers for needs for SMEs*
Who should be involved in the process? A role is missing for someone that can take care of environmental aspects as it is done for quality, better communication and inclusion of other actors like customers.	*Who should be involved in the process?* Customers through follow-ups.
Who should be involved in the decisions? Designers.	*Who should be involved in the decisions?* Sales, after sales personnel.
How should environmental factors be addressed?	*How should environmental factors be addressed?*

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Energy efficiency should be used more as an indicator, need to see suppliers' environmental impact, LCA training.	Environmental parameters that give points in concept review.
How should economic factors be addressed? There is no financial motivation in investing in environmental issues today.	*How should economic factors be addressed?* Difficulties in analysing profitability of new offerings.
How should uncertainties be addressed? Government officers and designers need better understanding of uncertainties of product development. Certain arguments that can be difficult to prove technically but can still weigh heavily by providing other background information such as customer surveys.	*How should uncertainties be addressed?* Better sort, analyse, evaluate ideas of new offerings and planning.
What support is needed? FMEA should be used more, shorter lead time, support to choose right material. Better communication from the beginning so tools or methods should aim at facilitating communication.	*What support is needed?* Support for better communication and GRI reporting.
What training should be provided? Life cycle thinking, how to manage product development, on existing products bring experiences rather than analyse concepts.	*What training should be provided?* Project management. There is a need to educate the customer, also people from government, of why paying for a premium product that is more resource efficient instead of only focusing on price.

5 ANALYSIS OF RESULTS AND DISCUSSION

5.1 Similarities

Table 2 and 3 show similarities in some type of support, e.g., FMEA, A3 reporting and ISO 14001. What is also worth noting is that in both cases decisions are made in board meetings or steering groups where project continuation, scale of a project, or offering niche is decided. These decisions are mainly based on the financial motivation or profitability of the offering as expressed by both large and SMEs. Other similarities include mock-ups, tests, or pilot studies to analyse an offering. Also, both types of companies can be ISO 14001 certified and in need to communicate their environmental sustainability to different stakeholders. Communication was a recurring theme for both types of companies. An important similarity is also found in project management skills, this can be reflected by their need to reduce lead time. Another similarity is that there seems to be little motivation for companies to further invest in environmental aspects since customers in several markets do not demand them or prioritize them.

5.2 Differences

Table 1, Table 2 and Table 3 provide some differences which confirm previous research (see: Deutz *et al.*, 2013). For instance, a formal product development process is in place in large companies. SMEs usually do not have a formal process. This could be explained in part because the number of employees is fewer and employees will carry tasks in different functions as opposed to large companies where well-defined responsibilities are in place and product design and development processes are carried out by a much larger number of employees. Also, the business owners in small companies are directly involved in many of the businesses' operations which is not the case for large companies. Uncertainties seem to be addressed more formally in large companies whereas smaller ones tend to go for gut feeling or rely heavily on key personnel, for instance, the owner of the company.

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5.3 Discussion

The analysis of offerings seems to be made continuously through product testing, mock-ups, lab tests, LCAs and economic calculations. Evaluation can be suggested to be done through a board of experts or senior managers, a steering committee which decide on whether a project should continue. It is also clear that in many cases customers, marketing, sales personnel are partially involved, and companies would like to include these stakeholders more through better planning and communication. The results show that it is important that support addresses how an offering is more resource-efficient but especially profitable. This is not trivial since in most cases the customer does not seem to be ready to pay for premium products and in some instances do not know how to use an offering in a resource-efficient manner. Moreover, education or training seems to be needed not only by companies but also suppliers, customers and in some cases government itself. Additionally, MCDM methods were not mentioned which points at an opportunity to integrate them to help companies address uncertainties much earlier in their analysis and add another dimension to what they currently do through mock-ups, lab testing and, in some cases, just gut feeling. In this regard, Figure 1 depicts how support could potentially reduce lead time. Analysis starts early in the design process until an evaluation is done by decision makers at board meetings. If relevant stakeholders are included in analysis and evaluation and further support is provided there is a potential to reduce lead time.

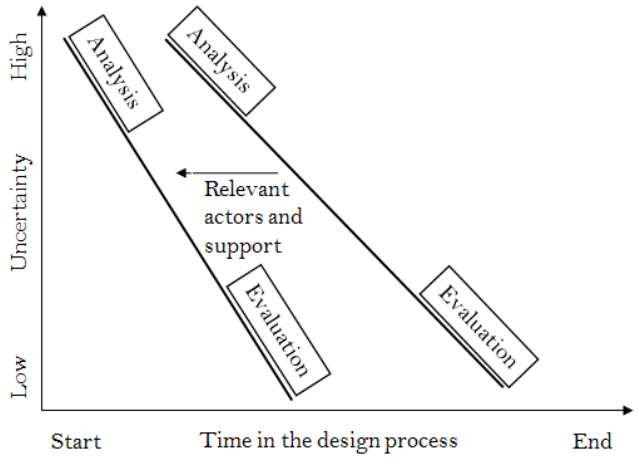

Figure 1. Reduction of lead time through support in analysis and evaluation

6 CONCLUSION AND FUTURE RESEARCH

This paper aimed at finding similarities and differences among large companies and SMEs. Based on the results, different support for analysis and evaluation can be discerned. For instance, analytical support used in practice for large companies include: LCA, LCC, product testing, risk analysis, calculations using spreadsheets and virtual testing. Support for Evaluation in large companies consists of FMEA, QFD, checklists, A3 reporting and ISO 14001. In turn, SMEs' analytical support used in practice cover: Product testing and risk analysis. Support for evaluation is based on: design for disassembly, FMEA, ISO 14001 and A3 reporting. The results do not show any use of the MCDM methods reported in literature. This could be explained by companies not being aware of these methods, lack of knowledge, or their usability. It is also important to notice that evaluation takes place at board or steering meetings and relevant stakeholders and support applicable to these settings could potentially reduce lead time and uncertainty in analysis and evaluation. Future research could then expand these findings to other activities in the designing of offerings to cover how companies develop conceptual designs or how they gather customer requirements. Additionally, support that can help companies in evaluating offerings based on MCDM methods presents an opportunity to identify reasons for their lack of use and further investigate usefulness and usability of such methods through possible follow-ups.

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