UNDERSTAND THE DESIGN REQUIREMENT IN COMPANIES

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Abstract

Design requirement identification is often the initial step in the product development process, for market-pull cases. Understanding the nature of design requirements and the sources, from where they can or should be captured, is critical to minimise this risk of generating poorly defined requirements. However, a clear view of the sources for eliciting design requirements is still lacking in academic studies, especially in the engineering design field. Hence, the aim of this paper is to better understand design requirement type and design requirement source, and to explore the interconnections between them through empirical studies. The research consisted of primary case studies in three Danish manufacturing companies and secondary data from a survey with 93 valid answers from the industry. The research findings enriched the understanding of where and how design requirements can be identified. This knowledge can be used to support companies to focus their efforts on the right sources according to the specific context. The development of a design requirement source-type model together with supportive toolboxes is suggested as the next step for further research.

Keywords: Requirements, Early design phases, Design practice

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1 INTRODUCTION

Often product development processes, in the market-pull cases, start with identifying the needs or problems that the product is expected to satisfy or solve. The initial needs and problems should be formulated into abstract, unambiguous, traceable and validatable design requirements (Brace and Cheutet, 2012). Design requirements coordinate the diverse desires in the end product and provide the basis of synthesizing a solution (Darlington and Culley, 2004). Various studies have been conducted in the engineering design field both descriptively to comprehend the design requirement practice, and prescriptively to improve practice through developing theories and methods etc. (Darlington and Culley, 2002). Several procedures for developing design requirements have been proposed in literatures e.g. (Dieter and Schmidt, 2007; Pahl, et Al., 2007; Ulrich and Eppinger, 2011).
Poorly identified design requirements can lead to inappropriate products (Hall, et al., 2002). Understanding the nature of design requirements and the sources, from where they can or should be generated, is critical to before developing methods and processes to support this process. Requirement Engineering research, originated from the software development field, highlights the traceability of design requirements e.g. (Grove, et al., 2005), which also implies the significance of recognizing design requirement sources. However, a clear view of the sources for eliciting design requirements is still lacking, especially in the engineering design field. Therefore, this paper intends to investigate potential design requirement sources and the contribution and challenges of each source. The research question investigates a way: how do design requirement sources contribute to the final design requirement set?
The paper is structured as follows: Section 2 presents the relevant literatures. The research methods are given in Section 3. Section 4 and 5 displays the results from case studies and a survey study. Section 6 discusses the findings and Section 7 concludes the paper.

2 DESIGN REQUIREMENT TYPE AND SOURCE

Design requirements are categorised in various ways. A common approach (especially in the software engineering field) is to differentiate them into functional requirements and non-functional requirements (Sommerville, 2011). Chen & Zeng (2006) grouped design requirements into eight levels: natural laws; social laws and regulations; technical limitation; cost, time and human resource; basic functions; extended functions; exception control level; and human-machine interface. Gershenson and Stauffer (1995, 1999) proposed a taxonomy containing four design requirement types indicating the origins of those problems, needs, and constrains:

- *End user requirement:* users' expectations of the product's capabilities, aesthetics and usability;
- *Corporate requirement:* business issues and product lifecycle issues;
- *Regulatory requirement:* safety/health, environmental/ecological, disposal and/or political issues;
- *Technical requirement:* engineering principles, material properties and physical law etc.

This taxonomy was selected as the basic for this study due to its relevance to design requirement sources. Four sources were implied by the taxonomy, namely the end user, the product, the society and the science (Gershenson and Stauffer, 1999). It simplified, summarised, and represented the complicated design requirement sources with the four ultimate sources. However, the correspondence between the four design requirement types and sources can be dynamic and context-dependent. For instance, users as a source may contribute to both end user requirements, e.g. a user friendly interface, and technical requirements, e.g. a certain specific material; conversely, an end user requirement may be generated directly from several sources e.g. the user source or by analysing competitors' products. Hence, mapping out the potential design requirement sources and their connections to design requirement types can contribute a better understanding of design requirement practice, and optimized methods application to different context, and hence improve the completeness and accuracy of the requirement identification.
Several research studies use the term 'stakeholders' to refer to human sources for generating design requirements, e.g. customers, marketers, and designers (Brace and Cheutet, 2012). Sudin et al. (2010) proposed a way to categorise design requirement sources into two groups: 1) human sources, namely clients, end user, market analysis report, colleagues, the designers' expected solution, and the designer's own requirement; and 2) artefact sources, namely semi-developed specification, proposed solution, existing product, previous project, design guideline, user guidelines. This categorization

recognises the non-human sources that are excluded in stakeholders. This recognition extends the information capture boundary beyond a single project's scope. For instance, the project team can learn from the existing products both from their own company and competitors (who are normally be excluded as stakeholders). Similarly, Wootton et al. (1997) separated the sources into individuals (e.g. customer, user or supplier), written materials (e.g. book, trade journal, or technical manual), and objects (e.g. competitors' products), and suggested to differentiate the sources into internal and external sources.

The authors' previous research (Li, Zhang, & Ahmed-Kristensen, 2014) identified seven sources based upon literature study: corporate, technology, user, market competition, regional infrastructure, organizational infrastructure, and regulation. They distinguish the internal and external sources and highlight their market dependence, which can support companies to recognise and prepare for changes when developing for a new market.

Thus, this paper aims to better understand the design requirement type and source, and to explore the interconnections between them through empirical studies, which indicates the path how each source contribute to the final design requirement sets The two concepts are clarified as:

- *Design requirement type* categorise requirements, indicating who or what is calling for the requirements.
- *Design requirement source* describes the requirement origin, from where the relevant information is captured.

3 RESEARCH METHODS

The research included both primary data from three case studies and secondary data from a survey study with 89 answers. The case studies were designed to gain an in-depth understanding of design requirement practice in the case companies through interviews and documentation analysis. Only part of the survey results relevant for this research is presented here. The following part of this section describes how the primary data was collected and analysed, whereas the detailed information about the survey can be found in (Li and Ahmed-Kristensen, 2015) and is summarised here. The survey contained 28 questions and was sent to Danish companies. 131 answers from 17 large companies, 19 medium companies, 66 small companies, and 29 micro companies were collected. 89 answers provided an insight into the generation of design requirements in a western context, and 64 provided insights into both western context and emerging markets. The primary data were collected in three companies, one large company and two SMEs, referred hereafter as Company A, B and C. They were chosen for this study as they are all Danish companies which develop physical products and were interested in product development for emerging markets. The comparison provide an explorative understanding of the practice in Danish SMEs. In total, five semi-structured interviews were conducted with individuals with the knowledge and experience of design requirement in the companies. Each interview was around 90 to 120 munities and they were all audio-recorded.

Company A is a 13 years old large size company with over 500 employees. They develop medical devices for professional users. They do business all over the world while currently the biggest share comes from the United States and their second biggest market is China. Three interviews were done in this company with one product manager, one project manager, and one technologist (who has professional knowledge in the field). In addition, design requirement documents and system specifications for one specific project were included to support the analysis.

Company B was founded in 2012 and has eight people including full-time, part-time employees and internships. They produce coating equipment for academic research use. Their customers are mostly in Europe but they are expanding to China and other emerging markets. The director (co-founder) from the company was interviewed.

Company C is a micro size company (and can be described as a start-up) with three employees and three freelancers, and was started in 2012 and has. They design health care products for adults who are not able to take care of themselves, and sell to both healthcare systems and private users. Their first product was under development and planned to be ready for sale in 2015, which was mainly tested in Danish market. The company intends to develop for emerging market soon. The interview was conducted with their director (co-founder). In addition, their design requirement document was analysed.

Each interviewee was asked to describe design requirement processes, sources, methods and challenges in general in their companies. They were required to order the importance of each source and estimate the contribution from each source to the final requirement set. For each case, the design requirement sources identified through the interviews and documents analysis were mapped together with their contribution to the four types of design requirements proposed by Gershenson and Stauffer (1995). The mapping was done according to interviewees' descriptions of the sources and their contribution. The map for company A was validated by the technologist.

Table 1. Data overview

Company	Company age	Number of employees	Document	Interviewee	Years at the company
A	13	> 500	1 design requirement 1 system specification	Product manager	2
				Project manager	11
				Technologist	12
B	2	8	N/A	Director	2
C	2	6	1 design requirement	Director	2

4 DESIGN REQUIREMENT IDENTIFICATION: FROM WHERE TO WHAT?

The analysis focused upon comprehending and demonstrating the design requirement types and sources, and the links in-between. This section presents the results from three case studies. For each case, the sources involved, methods applied, documents written and links to design requirement types are illustrated in one figure and explained in text. The various considerations from the interviewees are raised in the discussion.

4.1 Company A

Company A applied a standard and formal stage-gate product development process together with concepts from Agile Development. A product manager, a project manager and a technologist worked together to define requirements across projects. They formed a team referred to as the product owner in Agile. In this team, the technologist carried the main work of collecting requirements, especially user requirements. Figure 1 was drawn to demonstrate the design requirement sources, methods, types and documents in Company A integrating data from three interviews and two documents.

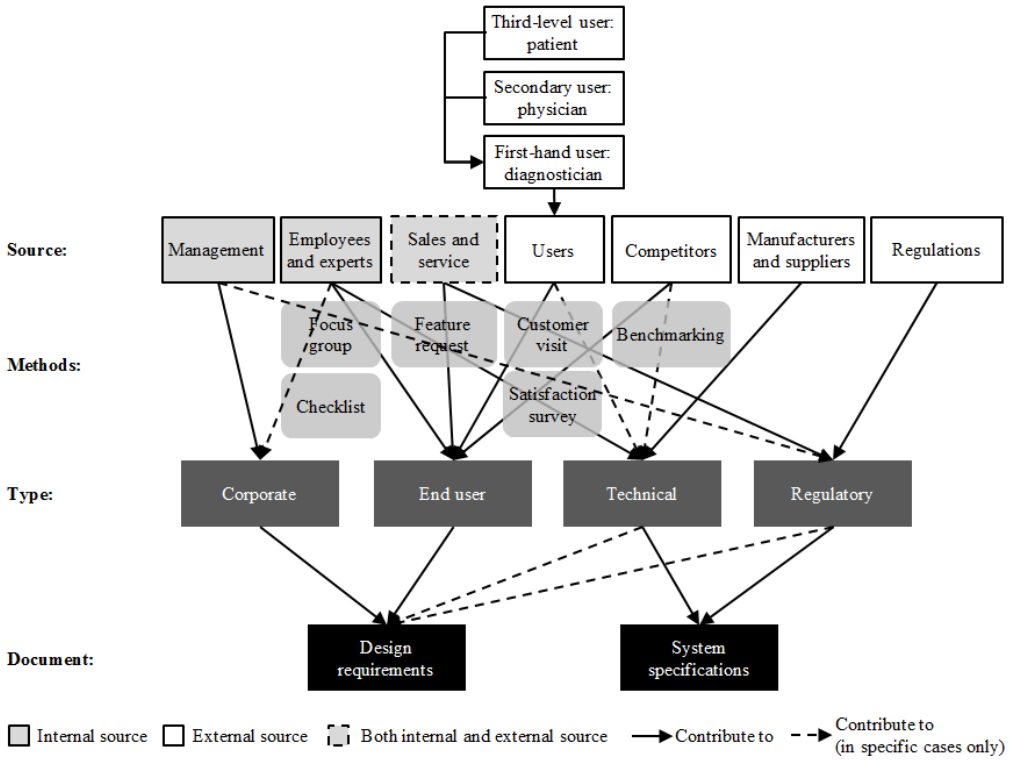

Figure 1. Design requirement practice in Company A

Seven sources were involved in the company's product development projects, including one internal source:

- Management: requirements from this source were typically aligned with company strategies and policies. For instance, the management team required a distinctive design from the existing products for strategic reasons. It had an indirect contribution to regulatory requirements by deciding which market the product would be sold to. This source was normally involved from the beginning of the projects. All three interviewees agreed that this source had a small contribution to the final number of requirements but it was very influential especially for an internal driven project.

Two mixed sources:

- Employees and experts: this source included the in-house employees as well as the external experts who were in a close relationship with the company. It was described as the most vital source for design requirements. The product manager said roughly 50% of design requirements were from this source and the technologist stated that it together with competitor source could contribute to about 90% to 95% of design requirements. In addition to the in-house idea generation, the company organised focus groups to gather experienced people. They were mostly from the company although sometimes external experts were included. Furthermore, a checklist was used to guide the design requirement identification. This source contributed to the end user requirements and technical requirements by bringing their experience and understanding of users and the technology into the design, and could indirectly influence company's strategies.
- Sales and service: the source covered both internal company departments and external partners. Their knowledge contributed to design requirement through a feature request system. In addition, when doing business in an unfamiliar market, the external sales partners supported the company to identify and understand the local regulations.

And four external sources:

- Users: this source was crucial but with a small contribution in terms of the number of requirements. It was not just a source for capturing information but also used to validate identified requirements. The technologist grouped their users into three levels. The first-hand user (diagnostician) operated the products directly; the secondary user (physician) used the information from the audiologist; and third-level users (patient) received treatment according to the information. Neither secondary nor third-level users used the products directly but were influenced by the products. Generally, a technologist visited the first-hand user and collected information about other users through the first-hand users. Satisfaction survey were used to gather users' opinion. In rare cases, professional users also requested specific technical requirements.
- Competitors: as mentioned, competitors together with employees and experts were the two main sources for design requirements in Company A. Competitors could not be involved directly in the project as stakeholders, instead their products were monitored and analysed. The requirements captured from this source were often validated by users. Technical requirements can in some case be generated from competitors, for example the new technology was applied in their products.
- Manufacturers and suppliers: this source mainly contributed to engineering considerations e.g. design for manufacturing. Both its importance and contribution were at a low level compared with other sources. This result was unexpected as literatures showed that manufacturing was the main cause for engineering change (Kanike and Ahmed, 2007). It indicated that manufacturing was not recognised as important as it would be in the design process.
- Regulations: this source included regulations, rules and industry standards etc., which was particularly critical for medical products and had to be strictly followed. But in term of quantity, its contribution was small.

In company A, the collected information would be first written into the design requirements then specified into the system specification. The project manager believed that the end user requirement were the core and formed about 75% of the design requirements. Regulatory and technical requirements were only briefly mentioned in the design requirements but clarified in system specifications, unless special issues were raised by other sources. The technologist viewed the users as the fundamental source for innovations. He gave an example that an innovative idea was initiated internally by the management team which turned out to be an unsuccessful product to the market.

Two key challenges in design requirement identification were underlined in the interviews: 1) to be innovative and to take big steps instead of cutting off small corners; 2) to achieve an agreement among various stakeholders.

4.2 Company B

Company B sold around 10 units per year and had 5-10 projects going on at the same time. It had two types of product development: customer-driven projects and internal-driven projects. For the former, design requirements were set at the very beginning within one or two months (for a one-year-project), while for the latter, the design requirement identification could be done in one week. The company did not apply formal development processes but consulted concepts from Agile Development. Two directors were in charge of the design requirement identification and their roles were not clearly distinguished.

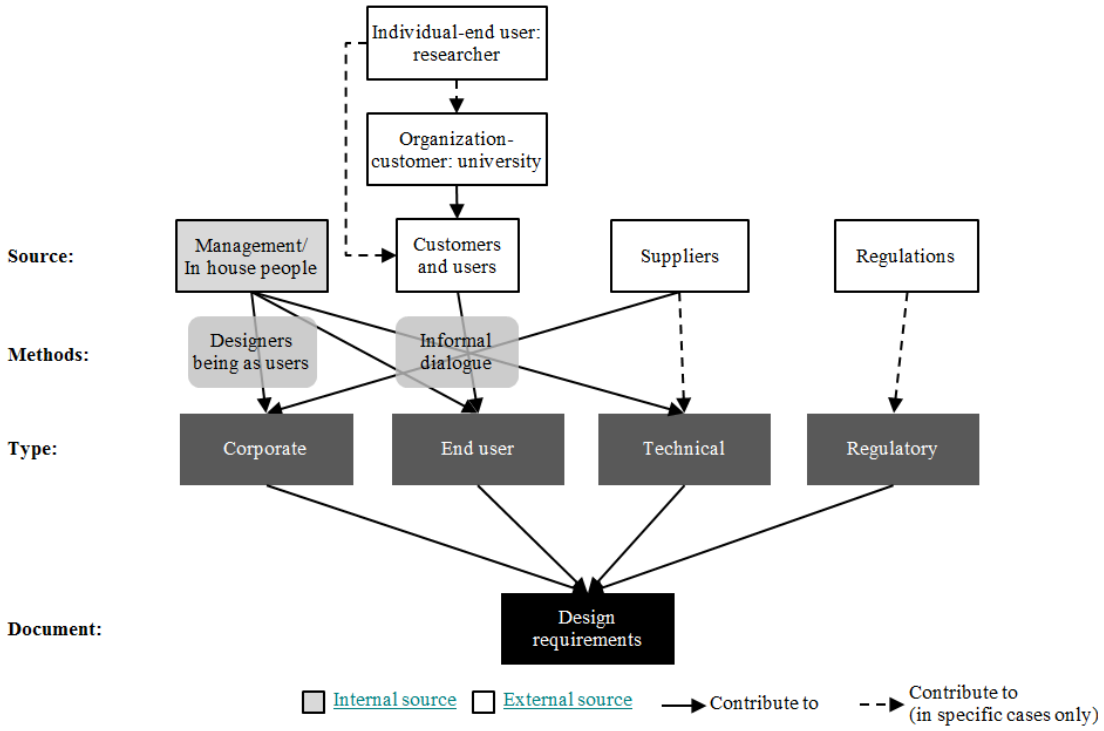

Figure 2. Design requirement practice in Company B

As displayed in Figure 2, the design requirement practice map in Company B involved fewer factors than that in Company A. Four sources were pointed out, with one internal source:

- Management and in house people: the management and in house people were not separated as two different sources because of their mixed roles in the small company. This source contributed to end user requirements by thinking around the table what the customer would want (known as designers being users approach) where the requirements were left board and open for customers to narrow down. They also contributed to corporate requirements by proposing company strategies. For instance, a distinctive colour scheme was required in order to make the products identical and eye-catching. In addition, their engineering knowledge was a source for technical requirements.

And three external ones:

- Customers and users: the customers for the company were the organisations (universities) that bought the equipments and the users were the individuals (researchers) who run them. Customers had the biggest contribution to more than 60% of the design requirements. It was especially true when the projects were customer-driven, where the customers initiated the requirements. The information was collected through informal dialogues, e.g. emails and meetings. Occasionally, they had also chances to communicate with individual users and gain direct feedback.
- Suppliers: in some projects, suppliers supported knowledge for finding out appropriate technical solutions, which was typically related to cost efficiency.

- Regulations: regulations had a limited contribution to design requirements in this case. The company tried to minimise in certifications due to cost concerns. In addition, if the customer agreed to take the risks, some regulations would not be addressed.

The company run in a niche market, where very little direct competition was currently taking place. They occasionally were inspired by the very hi-tech competitors. However, no specific requirements were from this source due to the limited access to expensive competitive products.

A key challenge emerging from the interview was to define a suitable cost strategy for supporting design requirements collection. As the customer driven approach, development started once an order was placed. Hence, an over quoted price might shut down the door in the beginning, whereas a low cost estimation would reduce the profit of the company.

4.3 Company C

Company C had not yet a product on market the development of the product was still under progress. Their process was informal and under improvement. The design requirements identification was carried out primarily by the director and sometimes involved student helpers. About half of the director's working time had been spent on collecting requirement data since the project started.

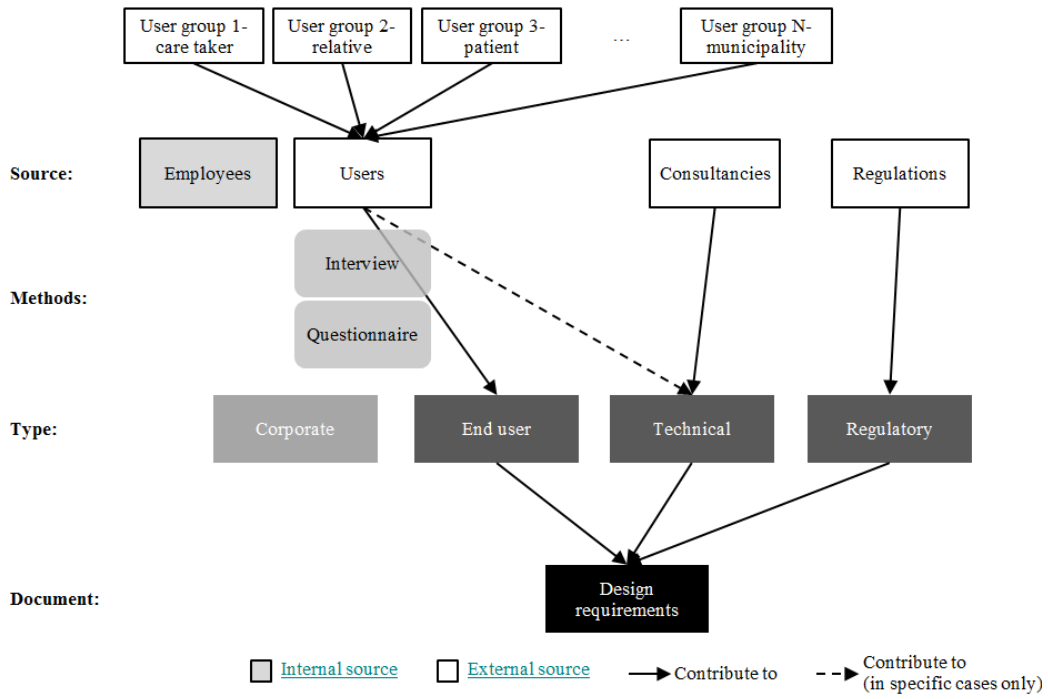

Figure 3. Design requirement practice in Company C

Three main design requirement sources were indicated from the interview. Employees as a source was added to the map (Figure 3) as it was assumed that their knowledge at least would have indirect influence on the requirements. However, this was not recognized by the interviewee, and the contribution of this source was not clear. Hence, the three external sources are described here:

- Users: this was the essential source for design requirements in this company. A few groups of users were defined according to their interactions with the product e.g. care takers and the patients. Huge amount of efforts were devoted to collect information from the various users. Questionnaires and interviews were conducted during the process. This gained the core insights for end user requirements and their questions about technology also contributed to the technical requirements.
- Consultancies: the company worked with two consultancies, which dealt with engineering and manufacturing issues. The comments they made on the design requirement document had a considerable contribution for the technical requirements (was indicated through document analysis). However, this contribution was not recognised by the interviewee.
- Regulation: some regulations were mentioned to be followed. Nevertheless, they were not of high priority in development but more for preparation of expanding to other markets.

This case displayed a strong user-driven project. A clear focus was on contacting and knowing all kinds of users and potential users. Data indicated very limited corporate requirements.
As a start-up, their approaches were explored through a learning process. As commented by the director: *'I didn't have an exact method when I started analysing the data. I used it in the process in order to get the right knowledge and information'*. Consequently, one key challenge for them was to access to the right people and find the right way.

5 DESIGN REQUIREMENT SOURCES: CONTRIBUTION AND DIFFICULTY

This section presents the result from the survey study that implies a general understanding of the difficulty level of each design requirement source and its contribution to the final requirement set. In the survey, respondents were asked to rate the seven design requirement sources, which were defined from literatures (Li, Zhang, & Ahmed-Kristensen, 2014) following two questions:

- How much do the following (sources) contribute to developing design requirements in your product development projects?
- When developing products for the Danish market, how difficult is it to identify design requirements from the following considerations (sources)?

The average score from 89 answers were calculated and illustrated. Figure 4 mapped out the seven sources according to their average scores for two dimensions: difficulty and contribution. Three sources: user, regulation and technology, were highlighted as having a big contribution and also high level of difficulty to act. Similar result was gained in the interviews for the user source and one reason was indicated as the complexity of the user groups. However, technology did not get much attention and regulations were not regarded as a challenge in the interviews. The market competition source in general contributed less than the other sources but was rated as the most difficult one. One explanation was the challenges to access to competitors' products and information, which was implied by the interviews as well. For instance, Company B could not analyse competitive products due to the high cost of their products. The regional infrastructure was rated as the least difficult with also the least contribution. This was also consistent with the case studies, where the infrastructure did not gain much attention. Company A integrated infrastructure considerations with their sales and service; Company B left infrastructure issues to customers; and Company C did not separate it from the users. Hence, it can be argued whether it is more reasonable take infrastructure as a separated source or integrate it with other sources, e.g. user.

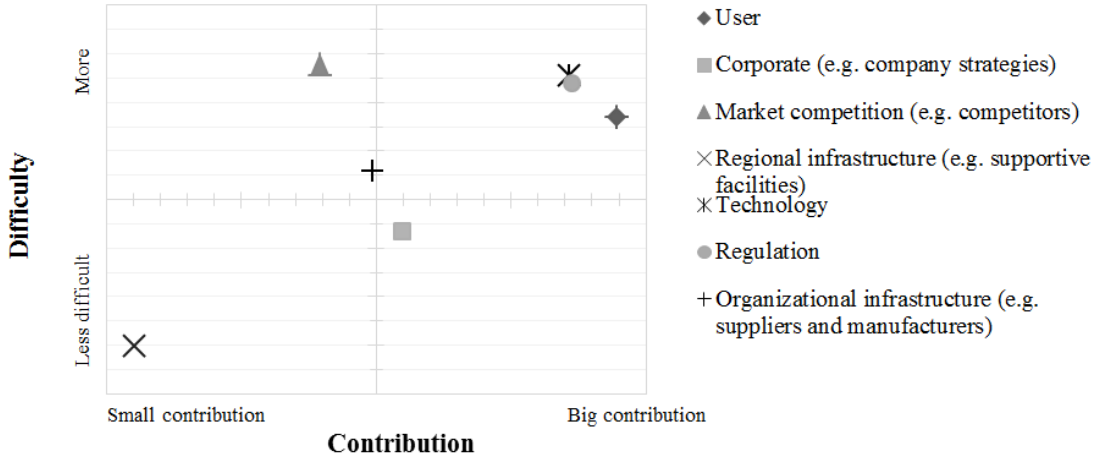

Figure 4.The difficulty and contribution of design requirement sources

6 DISCUSSION

The presented results indicate a few patterns of how companies identify design requirements and bring the confusing subjects into discussion. First of all, the research supports the view that design requirements require comprehensive information from multi-sources, e.g. (Wootton et al., 1997; Li et al., 2014). Indeed, when categorising design requirements into the four types, namely end user, corporate, technical and regulatory (Gershenson and Stauffer, 1995), each type of design requirements

can have input from several sources whilst each source can contribute to more than one type of design requirements. The links between source and type are context dependent.
Second, the case studies show the confusion of understanding the design requirement type and source in companies, where the requirements for users and from users are always mixed up. Hence, distinguishing the end user requirements and the user, as a requirement source including customer is necessary. The former designates a requirement set that can be attributed to the product users, while the latter, as an information source, provides insights into requirements. End user requirements are not necessarily solely from the user source. Among existing studies, end user requirements, also referred to as customer requirements, are commonly accepted as critical and crucial to the success of product development (Chen et al., 2003; Jiao and Chen, 2006; Morkos, et al., 2014). Its significance was verified both in the survey study and with the cases. In addition, the research shows that companies sometimes focus on end user requirements without recognising the other types. Quite a few studies on the end user requirement focus upon eliciting information from the user sources. Methods such as interview, focus group and survey have been frequently cited when approaching to users (Wood and Otto, 2000; Dieter and Schmidt, 2007). Nevertheless, the inputs to end user requirement from other sources are often omitted or neglected. In the research presented, the contribution to end user requirements from in house people and competitors is clearly revealed. In particular cases, those sources can contribute more than the user source to the end user requirements according to the product type and the project's nature. This raises a need for acknowledging the requirement collection methods from different sources, e.g. benchmarking (Zairi and Leonard, 1996) and functional decomposition (Clarkson et al., 1999) for understanding requirements from competitors.
Thirdly, the research illustrates the complexity of user sources for design requirements. In all three cases, the user source was described with subgroups. The extension can be vertical through a few levels of users and gather user information through one or more levels, or horizontal with several types of users and interaction required with each type. The extension shaped the way that company access users and the time and effort they spent on it. User identification is necessary for both access the right user group and to gain supplement user requirements from other sources.
Therefore, the research raises two issues: the understanding of the product nature and project type, and the awareness of available resources. Design requirement identification is a context dependent process, knowing your own situation is the precondition to start. The product and project prioritise design requirement types and indicate their likely contributions. Awareness of the existence of different types of design requirements is meaningful, instead of only concentrating on user requirements. For instance, regulatory requirement may only contribute to a very limited part to the final requirements but it can be crucial dependent on the industry sector, e.g. medical devices. Moreover, mapping out the available resources both internal and external can support companies to find the links between design requirement sources and types. For example, large companies might have a rich internal source for experience and knowledge while small companies can take advantages of more external sources, such as partners and consultancies. Finally, effective methods need to be developed and applied appropriately to elicit requirement from different sources.

7 LIMITATION

One drawback of the study was the case selection. The three case companies were varied in size and business scale, which was clearly not enough to represent the whole picture of Danish manufacturing industry. It was in particular challenge of gathering data from small companies due to their tight agenda and strained resources. However, the study was intended to explore some patterns of design requirement practice in companies. The results should be validated and generalized with a larger sample. In addition, data from 89 companies collected in the survey supported the studies and confirmed part of the findings.

8 CONCLUSION

This research consisted of primary case studies in three Danish manufacturing companies (with five interviews and three documents.) and secondary data from a survey with 89 valid answers from the industry. The research clarified the definition of design requirement type and design requirement sources. In addition, it investigated the sources both from literatures and empirical studies. The requirement elicitation methods for each source employed in the companies were presented. The

possible interconnections from sources to four types of requirements were explored in the three case presented. The research findings enriched the understanding of where and how design requirements can be identified. This knowledge can be used to support companies to focus their efforts on the right sources according to the specific context. From the obtained data, insights were gained, which indicated several possible design requirement sources and a few patterns of how company make use of the sources. More cases should be involved in future studies to supplement the potential missing links and to generalise the result. The development of a design requirement source-type model together with supportive toolboxes is suggested as the next step for further research.

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