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Hall-Andersen, Lene Bjerg; Broberg, Ole; Christoffersen, Lars D.

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Lene Bjerg Hall-Andersen

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Author: Lene Bjerg Hall-Andersen

Supervisors: Ole Broberg and Lars D. Christoffersen

DTU Management Engineering
Work System Design
Produktionstorvet, building 424
DK-2800 Kgs. Lyngby
Denmark

ALECTIA A/S
Teknikerbyen 34
DK-2830 Virum
Denmark

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Summary

Integrating ergonomic knowledge into engineering design processes has been shown to contribute to healthy and effective designs of workplaces. However, it is also well-recognized that, in practice, ergonomists often have difficulties gaining access to and impacting engineering design processes. This PhD dissertation takes its point of departure in a recent development in Denmark in which many larger engineering consultancies chose to established ergonomic departments in house. In the ergonomic profession, this development was seen as a major opportunity to gain access to early design phases.

Present study contributes new perspectives on possibilities and barriers for integrating ergonomic knowledge in design by exploring the integration activities under new conditions. A case study in an engineering consultancy in Denmark was carried out. A total of 23 persons were interviewed in the consultancy, involving CEOs (N = 2), ergonomists (N = 10) and engineering designers (N = 11). The interviews were supplemented by observations and document studies. The analysis activities were based on a combination of inductive and deductive approaches. The theoretical framework includes perspectives on learning and knowledge management and theoretical concepts of objects derived from Science and Technology Studies. This combination of theoretical perspectives is new with this area.

In the engineering consultancy setting the proximity, which arose from the ergonomists and engineering designers being employed in the same company, constituted a supporting factor for the possibilities to integrate ergonomic knowledge into the engineering design processes. However, the integration activities remained discrete and only happened in some of the design projects. A major barrier was related to the business-driven design context and its constant focus on maximizing the profit of the individual design projects. This barrier was strongly reinforced by focal points in the performance measurement system. In this business-driven setting, possibilities to integrate ergonomic knowledge in design projects can be linked to the ergonomic ambitions of the clients. The ergonomists' ability to navigate, act strategically, and compromise on ergonomic inputs is also important in relation to having an impact in the engineering design processes. Familiarity with the engineering design terminology and the setup of design projects seems to enhance the ergonomists' ability to act in design.

The study also focuses on the important – but often unrecognized – role that objects can play during integration activities. In the direct communication between ergonomists and engineering designers, objects can help to facilitate a dialogue across the knowledge boundaries between the actors. However, objects used as means of transferring ergonomic knowledge over a distance face difficulties in performing a distant effect, hence they should be supported by inclusion of an ergonomist who can assist, for instance when different design criteria conflict.

Additional findings and implications are presented and discussed in the overall thesis and in the four articles which constitute the dissertation.

Resume

Inden for arbejdsmiljøforskningen viser mange undersøgelser, at inddragelse af arbejdsmiljøhensyn tidligt i designprocesser kan bidrage til at skabe både sunde og effektive arbejdspladser. Det er dog også en udbredt erkendelse, at arbejdsmiljørådgivere i praksis ofte har vanskeligt ved at få adgang til og indflydelse i design processer. Denne ph.d.-afhandling tager udgangspunkt i en forholdsvis ny udvikling i Danmark, hvor mange af de større rådgivende ingeniørfirmaer har valgt at etablere en væsentlig arbejdsmiljøkompetence inden for firmaets egne rammer. Inden for arbejdsmiljøforskning og blandt arbejdsmiljørådgivere blev den nye udvikling set som en oplagt mulighed for at få adgang til tidlige design faser.

Med afsæt i arbejdsmiljøforskningen bidrager denne ph.d.-afhandling med nye perspektiver på muligheder for at inddrage arbejdsmiljøhensyn i design ved at fokusere specifikt på *muligheder* og *barrier* inden for rammen af et rådgivende ingeniørfirma. Projektet er baseret på et case studie i et rådgivende ingeniørfirma, hvor 23 personer er blevet interviewet, herunder CEO (N = 2), arbejdsmiljørådgivere (N = 10) og ingeniører (og andre faggrupper) (N = 11). Interviewdata er suppleret med observationer og et dokumentstudie. Analyser er baseret på en kombination af induktive og deduktive tilgange, hvor et teoretisk rammeværk bestående af forskellige perspektiver på læring og knowledge management samt udvalgte koncepter fra 'Science and Technology Studies' er anvendt. Denne kombination af teoretiske perspektiver er ikke tidligere anvendt indenfor dette område.

Studiet viser, at den nærhed som opstod mellem ingeniører og arbejdsmiljørådgivere, fordi de nu var ansat i samme hus, havde en positiv indvirkning på mulighederne for at bringe arbejdsmiljøviden med på banen i de tidlige designfaser. Integrationen af arbejdsmiljø i design vedblev dog at være spredt, idet arbejdsmiljørådgiverne blev inddraget sporadisk. En væsentlig barriere inden for rammerne af den rådgivende ingeniørvirksomhed var relateret til, at design-processerne i et rådgivende ingeniørfirma er forretningsdrevet og et konstant fokus på at maksimere overskuddet af de enkelte design projekter eksisterer. Denne barriere blev forstærket af virksomhedens organisering og deres nøgletalsevaluering.

I denne forretningsdrevne design kontekst synes mulighederne for at inddrage viden om arbejdsmiljø, at være stærkt relateret til kundernes efterspørgsel og deres vilje til at betale for, at en arbejdsmiljøvinkel bliver inkluderet i projekter. Mulighederne er også relateret til den måde arbejdsmiljøviden bliver bragt i spil i projekter og her udgør arbejdsmiljørådgivernes evne til at navigere og forhandle sig til en plads i design projekter en væsentlig rolle. At kunne navigere og handle på en måde, så de arbejdsmiljømæssige input bliver forstået og værdsat af ingeniører synes at kræve kendskab til både design terminologi, projekt organisering, samt

ingeniørmæssige leverancer. Herudover er det afgørende, at arbejdsmiljørådgivere er åbne og villige til at indgå kompromiser omkring arbejdsmiljømæssige krav og anbefalinger.

Projektet bidrager også med et nyt perspektiv på, hvordan forskellige artefakter såsom layouttegninger og arbejdsmiljørapporter spiller en vigtig, men ofte undervurderet rolle, i forhold hvordan arbejdsmiljøviden nyttiggøres i design processer. I den direkte kommunikation mellem ingeniører og arbejdsmiljørådgivere kan artefakter være med til at facilitere en dialog på tværs af deres respektive videns domæner. Artefakter bruges også som et led i at overføre arbejdsmiljøviden til ingeniører og andre faggrupper, uden at disse nødvendigvis mødes face-to-face. I denne rolle møder artefakter dog vanskeligheder og har svært ved at udøve 'kontrol' og sikre at arbejdsmiljø input bliver implementeret. Derfor bør artefakter, som har til opgave at overføre arbejdsmiljøviden til ingeniører være ledsaget af en arbejdsmiljørådgiver, som kan indgå i dialog og skabe kompromisser, når forskellige designkriterier er modstridende.

1 Introduction

Integrating ergonomic knowledge into engineering design processes has been seen for years as an important pro-active strategy to enhance good working conditions and production efficiency (Broberg, 2010; Dul and Neumann, 2009; Goggings at al., 2008; Hendrick, 2008; Jensen, 2002; Neumann and Dul, 2010; Oxenburgh et al., 2004). However, it has also been recognized that, in practice, it is often difficult for ergonomists to gain access to and have an impact on design processes (Broberg, 2007; Broberg and Hermund, 2004; Jensen, 2002; Perrow, 1983; Wulff et al., 1999a, 1999b). In Denmark, a recent development in the area of engineering consulting and Occupational Health and Safety (OHS) consulting has created new opportunities to integrate ergonomic services into engineering design processes. During the period 2005-2008, public funding for OHS services was phased out, and the area was privatized. At the same time, many of the larger engineering consultancies broadened their line of consultancy services by acquiring companies with OHS consultancy services. This meant that, in Danish contexts, engineering designers and ergonomists were now working within the same companies to a larger extent than before.

1.1 Background: Case company

The engineering consultancy ALECTIA was one of the engineering consultancies who acquired ergonomic competencies during this period. In 2006-2007, ALECTIA acquired two OHS consultancy companies as part of the company's newly established growth and differentiation strategy. The decision to acquire the OHS consultancies was based on a desire to have a greater palette of competencies with which to access the market, and make it possible to become a full-service consultant for clients. Moreover, the ambition was to be able to address the market with new commercial services that combined ergonomic competencies with the technical competencies already existing in company.

The CEO in charge of the acquisitions explained that her motivation for acquiring the OHS consultancies was also based on an experience she had shortly after entering the position in ALECTIA. She had attended the opening of a large-scale production site in Hillerød in Denmark that ALECTIA had participated in designing. She thought the production site was "very impressive", but while she walked around there, one of the managers at the production site discreetly pulled her aside. He said: "You do realize we have to start all over tomorrow. This is not at all designed for the people who are going to work here"(Interview - CEO). This experience contributed to opening her eyes to the prospects of integrating ergonomic competencies in design. The question of how to utilize the ergonomic competencies in relation to the engineering design processes still remained however.

The present PhD project was initiated to shed light on this question by focusing on related possibilities and barriers in relation to integrating ergonomic knowledge into engineering design projects within the setting of an engineering consultancy. The project was carried out as an industrial PhD project in cooperation with DTU Management Engineering and ALECTIA, partly funded by the ALECTIA-Foundation and partly by The Danish Ministry for Science, Innovation and Higher Education. Luckily for me, I was chosen as a candidate, and on May 1, 2009, the PhD project was initiated.

1.2 Background: Human Factor literature

This dissertation takes its point of departure in the research area of ergonomics, also often referred to as Human Factor (HF). The idea of integrating ergonomic knowledge in design is not foreign to the ergonomic profession; in fact, design is a central element in the ergonomic community's understanding of ergonomics.

Overall, ergonomics is described as being concerned with design of the interfaces between humans and other system components. The main purpose of the discipline is to improve human well-being, productivity and quality by minimizing human errors induced in design (Hendrick, 2008). The field of ergonomics can be characterized as multidisciplinary and includes such areas as psychology, applied physiology, environmental medicine and engineering (Wilson, 2000). This PhD dissertation takes its point of departure in a sub-area of ergonomics called 'macroergonomics'. Macroergonomics is "concerned with the analysis, design and evaluation of work systems" (Hendrick and Kleiner, 2002, p. 1), where *work* is characterized as any kind of human activity and *systems* are 'sociotechnical' systems. A sociotechnical system is here seen as consisting of interrelated components (e.g. people, processes and technology), which are dynamically linked in a transformation process for a given purpose (Siemieniuch and Sinclair, 2006). Wilson (2000, 2012) argues that above all ergonomics is a system-oriented discipline, where focus is on the *interactions* between the different components in a system.

1.3 Research focus and question

The overall purpose of this PhD project is to study the integration of ergonomic knowledge into engineering design processes. Putting a focus specifically on engineering designers and their practice is relevant, because engineering designers are leading actors in designing systems; as such, they are gatekeepers for input (Meister, 1982; Pikaar, 2007). While different aspects of integrating ergonomic knowledge into engineering design projects have been studied before, the new development in Danish engineering consultancies has made it possible to study the

subject under new conditions, namely in the organizational setting of an engineering consultancy. The importance of understanding the context within which ergonomic initiatives are introduced is stressed by Kirwan (2000) and Wilson (2000). A review of the HF literature showed that prior studies have not been given much attention to the context of engineering consultancies. The HF literature contains contributions and discussions regarding how ergonomics should work and how different ergonomic initiatives should be implemented in practice, but only a few studies focus on how ergonomists actually work in practice (Theberge and Neumann, 2010). The focus of this PhD project is on exploring different initiatives that aim to integrate ergonomic knowledge in engineering design processes through a "natural experiment" in ALECTIA, where the experimental conditions are out of my control. I believe that exploring how initiatives are carried out in a 'natural setting' and how different factors influence the integration processes can provide valuable insights into how to support future integration initiatives. One overall research question, together with three sub-questions, have guided the PhD study:

What are the possibilities and the barriers for integrating ergonomic knowledge in engineering design processes in the setting of an engineering consultancy?

Sub-question 1: Why is ergonomic knowledge not or only partly integrated into engineering design projects in the setting of an engineering consultancy?

Sub-question 2: How can ergonomic knowledge effectively be integrated in engineering design processes, in a way that is appreciated by engineering designers?

Sub-question 3: What does the integration require organizationally of the engineering consultancy?

1.4 Clarification of terms

Ergonomics

In this dissertation, the term ergonomics is used rather than such terms as working environment or Occupational Health and Safety (OHS). The term ergonomics is broader than both working environment and OHS. According to the International Ergonomics Association (IEA), ergonomics is defined since 2000 as follows:

> Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance (IEA, 2013).

The biggest difference between the term ergonomics and OHS/working environment is its focus on both "human well-being *and* overall system performance". I choose to use the term ergonomics, because it is broadly used in the literature, and I find the dual focus on both human well-being and overall system performance to be rather important. In this overall thesis and the related articles, the terms OHS and HF are sometimes used as synonyms for ergonomics.

Engineering consultancy and engineering design

The term 'engineering consultancy' should be seen in a Danish context, where ALECTIA is one of the larger engineering consultancies.

The term 'engineering design processes' refers to the work processes carried out during engineering design tasks, for instance in relation to building projects or the design of new production systems. In the engineering consultancy setting, engineering design tasks are mainly carried out in project teams consisting of engineering designers. In this study, the term 'engineering designers' refers to engineers with different areas of experience, but it also encompasses other professionals who work alongside the engineering designers in carrying out design tasks. These other professional can be design actors with various academic backgrounds or actors with a more practice-oriented education, such as nursing, who are hired by the company for their knowledge of specific business settings.

Engineering design is distinguished from other disciplines by a main focus on the technical aspects of a given system. When engaging in design, engineering designers are motivated by the aim of delivering systems that perform well in accordance with prevailing standards in their respective professional areas while living up to client requirements (Dul et al., 2012). This aim requires that various aspects are taken into account, such as different technical issues, budgetary limits and organizational or social aspects (Jørgensen, 2009). In the engineering community, design is often seen as a technical and rational process in which decisions are based on rational principles: "Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation" (Wulff et al., 1999a, p. 203). In contrast to this view of design, Bucciarelli (1994) sees engineering design as a social process in which each design actor can have quite different viewpoints on what an optimal 'solution' might be. Hence, the process of designing involves many negotiations and tradeoffs between different design criteria. Through this PhD project, I

have developed an understanding of design as being guided by a rational approach, while it in practice can be characterized as a social process.

When using the term 'dissertation' I refer to this 'overall thesis' *and* the four articles.

1.5 Delimitation

The overall focus of this dissertation is 'integration of ergonomic knowledge into engineering design processes within the setting of an engineering consultancy', where the main attention was paid to 'meetings between engineering design and ergonomics'. Throughout the study, other important actor groups such as architects and end users emerged in the data material. Given the main focus of this dissertation, however, the aspects related to architects and users are only briefly touched upon.

There are also many ways of stimulating the integration of ergonomic knowledge in design. One way that has not been a part of this study is to introduce ergonomic training as part of the education of engineering designers. While this approach would also be an interesting path to follow, the choice of an engineering consultancy as the study's main setting made the education aspect less relevant.

1.6 Structure of the dissertation

The results and findings of this PhD dissertation are presented in four articles, which contribute to different and valuable perspectives on the overall research question. The purpose of this overall thesis is to generate an overview of the findings presented in the articles, and discuss the contributions across the articles, in order to provide a more comprehensive answer to the overall research question. There are some repetitions and overlaps between the articles and the overall thesis, but generally the thesis provides more background information and more thorough descriptions and discussions than are possible in the research article format.

The thesis is structured as follows: Chapter 2 provides an overview of the 'state of the art' literature regarding integrating ergonomics in design. Chapter 3 presents the methodology. The theoretical framework is accounted for in chapter 4, and chapter 5 introduces the case company, ALECTIA. Chapter 6 provides an overview and resume of each of the four articles. In chapter 7, I look across and beyond the four articles and discuss the findings and the contributions of this PhD project. Finally, chapter 10 concludes the PhD dissertation and provides implications as well as recommendations for further research.

2 Integrating ergonomic knowledge in design

Several studies in the HF literature have been able to show the financial benefits of integrating ergonomic knowledge into design processes (Goggings at al., 2008; Neumann and Dul, 2010; Oxenburgh et al., 2004). It is widely recognized among ergonomists that, in order to achieve the greatest benefits, ergonomics should be integrated into design early in the design process, as this maximizes the possibilities of having a real impact on the design and reduces potential costs of redesign (Béguin, 2011; Dul and Neumann, 2009; Haslegrave and Holmes, 1994; Jensen, 2002). The rationale behind this argument is illustrated in Figure 1, which shows the temporal dynamics of the design processes.

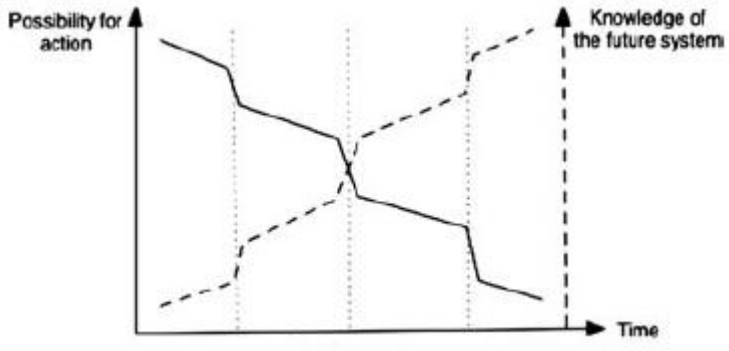

Figure 1: Progress of design processes (from Béguin, 2011, p 546)

Figure 1 shows that in the early stages of design little is still known about the future work system and many design options exist. As more knowledge is gained about the future work system, decisions are made, and freedom of action and design options are gradually reduced. After a certain point, it is no longer feasible to introduce modifications or changes. Therefore, the later ergonomic input is introduced into the design process, the greater are the constraints (Béguin, 2011). In engineering design, the predominant approach to design is to consider the shell of the building first, because this "…saves time (and therefore money), as the building site can be started while the engineers design the inside" (Béguin, 2011, p. 547, brackets in original). This approach clashes with what is considered ideal from an ergonomic point of view; the erection of new buildings and production facilities should ideally be designed on the basis of an analysis of the work processes to be carried out in the building.

Research has contributed a range of recommended models, methods and approaches for integrating ergonomics into design processes (e.g. Daniellou, 2005; Falzon, 2008; Jensen, 2002; Seim and Broberg, 2010). But despite the central role design is given in the ergonomic community, and the many recommended models and methods for integrating ergonomics in design, it is well-recognized that, in practice, ergonomists often have difficulties gaining access

to and impacting engineering design processes (e.g. Broberg, 2007; Broberg and Hermund, 2004; Jensen, 2002; Perrow, 1983; Wulff et al., 1999a, 1999b). Through a literature review within the field of ergonomics, Broberg (2007) identified two main types of approaches to integrating ergonomics in design: One approach focuses on providing ergonomic information to engineering designers; and another approach focuses on organizational factors in engineering design settings.

In the following, I focus specifically on research that shed light on possibilities and barriers for integrating ergonomic knowledge in design. I draw on Broberg's (2007) distinction, and add a third section about 'political processes and the role of ergonomists'. I do this to bring focus to the political aspects of integrating ergonomics in design and to bring focus to the important role ergonomists.

2.1 Information transfer strategy

The information transfer strategy approach focuses on providing engineering designers with information on ergonomics, for instance through the use of ergonomic standards. Several studies have found limitations in using this approach, however, including the problem that the approach seems to have a low effect in design processes (Broberg, 2007; Burns and Vicente, 1994, 1996; Burns et al., 1997; Campbell, 1996; Helander 1999; Meister and Farr, 1967; Rogers and Armstrong, 1977, Wulff et al., 1999a, 1999b, 2000). These contributions have identified such shortcomings as:

- Information overload
- Too weak or too general formulation of ergonomic criteria
- Low value of applicable information embedded in guidelines
- Low knowledge about ergonomic criteria among engineering designers
- Low perceived relevance and importance of ergonomic criteria and handbooks; while on the other hand, high perceived costs of obtaining information
- Resistance toward the ergonomic criteria among engineering designers
- The nature of the design process that the criteria are entering into, which can be characterized as being full of constrains and conflicting criteria

Rogers and Armstrong (1977) argue that the formulation of ergonomic criteria should be precise and preferably quantitative, and the use of "escape clauses" should be avoided. A similar argument is made by Wulff et al. (1999a, 1999b), who recommend the use of specific formulation, although they also conclude that this does not guarantee that the criteria will be implemented. In acknowledging design as a social process, they argue that additional organizational initiative should be introduced to support the use of guidelines, for instance by having an ergonomic professional actively engaged in the design process. Campbell (1996)

recommends that in order to make "clear, relevant and useful guidelines", knowledge about designers and the system design environment is needed, including knowledge about trade-offs and constraints. He also finds that in the development of relevant and useful guidelines, ergonomists need to apply their experience and judgments to existing data sources. Both Campbell (1996)and Burns and Vicente (1994) argue that to enhance the use of ergonomic information in design, it is important that ergonomists focus on providing information that is of value to the engineering designers and compatible with their needs and requirements. A pitfall of this strategy is that engineering designers might not appreciate the input that is highly relevant from an ergonomic point of view.

While the above recommendations are mainly directed toward the use of more traditional ergonomic standards, Conceição et al. (2012) contribute with a broader focus on how different objects can be introduced in attempts to transfer ergonomic knowledge in design. These authors report on a study in which two different types of objects were developed: a recommendation booklet and a zoning pattern, which were aimed at transferring ergonomic knowledge and user experience to engineering designers in the offshore industry. In this industry, face-to-face meetings between users and designers are often hard to arrange, which makes information transfer necessary. The recommendation booklet was developed on the basis of a thorough ergonomic analysis at operating platforms, and to the extent possible, all recommendations were supplemented by underlying explanations that could guide the engineering designers, if conflicting criteria should emerge. The zoning pattern was "a visual representation 'mapping' of the inter-relations" (Conceição et al., 2012, p. 130) among the different environments at the platforms. At workshops with engineering designers, the usability of the two objects was evaluated positively, and they were recommended for use in future design processes.

2.2 Social and organizational factors

Various contributions have provided valuable insights on how social and organizational factors affect possibilities for integrating ergonomic knowledge in design. In Perrow's (1983) classic paper, he points to the impact the organizational structure of a company can have on the possibilities for integrating ergonomics in design. He argues that ergonomists are often placed in a weak position organizationally, physically separated from the engineering design departments. At the same time, engineering designers are also often isolated organizationally from any possibility to learn about the unsuitable aspects of their designs. To promote the integration of ergonomic knowledge in design, Perrow (1983) points out the importance of ergonomics being included in top management goals and in the related reward systems that guide the designers. In a study at Volvo Powertrain, Neumann et al. (2009) also found that

initiatives to integrate ergonomics into production system design were complicated by organizational barriers, such as ergonomists not having access to decision-making processes.

Based on a study in the nuclear industry, Burns and Vicente (2000) characterize design as a "changing web of constraints from many sources". They report on constraints related to the specific design task, such as spacial constraints, but also structural constraints, which arise due to a division of the overall design project into sub-problems. This division is common in large-scale design projects and can cause coordination problems, because the sub-problems are interlinked, and when a decision is made regarding one sub-problem, it affects other sub-problems. Coordination problems are complicated additionally by the many different knowledge domains present in design projects. Haslegrave and Holmes (1994) also find that recommendations given at early stages of design can be changed at later stages, which calls for repetitions of recommendations throughout the design process. These authors also argue that design is a commercial discipline where "neither engineering designer nor ergonomist has complete freedom in arriving at design solutions" (Haslegrave and Holmes, 1994, p. 216). A similar argument is found in a conceptual paper by Béguin (2011), who describes design as a process of constrains – constraints that stem from design being a goal-oriented process with time boundaries, and constraints that are caused when different disciplines are engaged in a given design project. Béguin (2011) argues further that the analytical methods and the "human factor evaluation paradigm" underestimate the reality of design processes.

Studies also identify intergroup barriers between engineering designers and ergonomists that involve issues like a clash of perspectives and a lack of a common language with which to address design problems. These issues are typically ascribed to the fact that engineering designers and ergonomists have different mindsets and belong to different social worlds (Haslegrave and Holmes, 1994; Kirwan, 2000; Neumann et al., 2009; Wulff et al., 1999a, 1999b). Reported barriers are related, for instance, to conflicting design goals or engineering designers' and managers' perception of or attitude towards ergonomics, which is considered to be a strong determinant for whether or not ergonomic input is implemented in practice, because managers and engineering designers have a gatekeeper role in design (Broberg, 2007; Burns and Vicente, 2000; Kirwan, 2000; Meister, 1982; Waterson and Kolose, 2010; Whysall et al., 2006; Wulff et al., 1999a, 1999b).

Different proposals to overcome intergroup barriers are identified in the literature. One approach is related to providing ergonomic training to engineering designers and "engineering design" training to ergonomists (e.g. Haslegrave and Holmes, 1994; Neumann et al., 2009). These proposals are based on the rationale that increased understanding of each other's

practice and terminologies can help bridge the boundaries between practices. Neumann et al. (2009) also found that a cross-functional workshop, which had a specific focus on supporting discussions across organizational boundaries, helped create a shift from ergonomics being included in retrofitting of solutions to being introduced more proactively in design. Neumann et al. (2009) also focus on creating concrete ergonomic tools that can support engineering designers in their design work.

The workspace design approach, as described for instance in Seim and Broberg (2010), is introduced as a potential method to integrate ergonomic knowledge in design. Through the use of visual design methods, this approach has proved to be able to stage joint design processes across different knowledge domains. In Broberg et al. (2011), a specific focus is on the role of objects in participatory design processes. These authors found that objects that were both *flexible and malleable* enabled a participatory design process between a group of design actors that included users, an ergonomist and engineering designers. This was because it was possible to do rapid prototyping and test different design solutions on the spot.

2.3 Political processes and the role of ergonomists

Various contributions address to a varying extent more political aspects of integrating ergonomic knowledge in design. Based on a political understanding of technological design processes, Garrety and Badham (1999) argue that in sociotechnical design processes there will always be elements of negotiations and persuasion. In this environment, ideas or methods developed by ergonomists would never be able, by the weight of their own virtue, to diffuse into organizational settings. Models and methods can help "transfer of technologies across social worlds", but they need to be supported by ergonomists who engage in lobbying and negotiating solutions. Other important contributions argue similarly and suggest that ergonomists need to understand the structural and organizational barriers of integrating ergonomics in design in order to be able to act both within the process of design and on design, as design is not only an applied process, but also a political process (Béguin, 2011; Haslegrave and Holmes, 1994; Waterson and Kolose, 2010; Wulff et al., 1999a, 1999b).

In a valuable and often cited contribution, Broberg and Hermund (2004) suggest that ergonomists should consciously reflect about their own role in organizational change processes. Based on two case studies in a Danish context, they further suggest that assuming the role of "political reflective navigator" can be advantageous when entering into technological change processes in organizational settings. They describe this role as follows:

> "The consultant is *political* in the sense of pursuing a work environment agenda; the consultant is *reflective* in the sense of being able to switch between different roles and mobilize different types of knowledge depending on the context; the consultant is a *navigator* in the sense of knowing how to navigate in the complex organization surrounding the technological change process" (Broberg and Hermund, 2004, p. 315).

The idea of the ergonomist taking a more political role is suggested in a number of studies (e.g. Badham and Ehn, 2000; Jensen, 2002; Neumann et al., 2009). Based on an interview study with 21 Canadian ergonomists, Theberge and Neumann (2010) found that the nature of ergonomists' work was highly cooperative and that the notion of 'political reflective navigator' also applied for Canadian ergonomists, who used elements like 'goal hooking' (Poggi, 2005) and 'political maneuvering' in their work to promote the ergonomic agenda.

The idea of using goal hooking and strategically linking ergonomics to the goals of engineering designers or companies' overall business goals have also been suggested before (e.g. Dul and Neumann, 2009; Neumann and Dul, 2010). These studies suggest that we need a shift from ergonomics with a main focus on human wellbeing to a more business- oriented focus on linking ergonomics to business strategies. Based on studies in the defense industry in the UK, Waterson and Kolose (2010) also found that in attempts to break through organizational barriers, ergonomists sought to tap into the mindset of engineering designers and bridge the boundaries by presenting data in a manner that engineering designers would value.

Many other valuable contributes exist in the HF literature. The presented contributions were chosen to shed light on some of the main tendencies in the literature around integrating ergonomic knowledge in design.

3 Methodology

This chapter accounts for the different methodological choices made along the research journey. Although the description presented here is somewhat linear, the PhD process has been far from linear. Besides being based on thoughts about methods and methodological reflections, the contributions of this PhD project are also a result of what was practically possible at given steps in the PhD process. Hence, a pragmatic approach guided the research.

The overall purpose of this PhD study has been to gain an in-depth understanding of the possibilities and barriers related to integrating ergonomic knowledge into engineering design processes. When the purpose of a study is to generate in-depth understanding of a social phenomenon in an organization, methods and qualitative approaches like case studies, interviews and observation are appropriate (Kristiansen and Krogstrup, 2005; Thomas, 2011; Yin, 2009). In Figure 2 an attempt is made to illustrate graphically how the research process unfolded, where the arrows illustrate the iterative nature of the research process. In the following sections, I account for the different choices made during the course of the research process by focusing on the individual steps in the model.

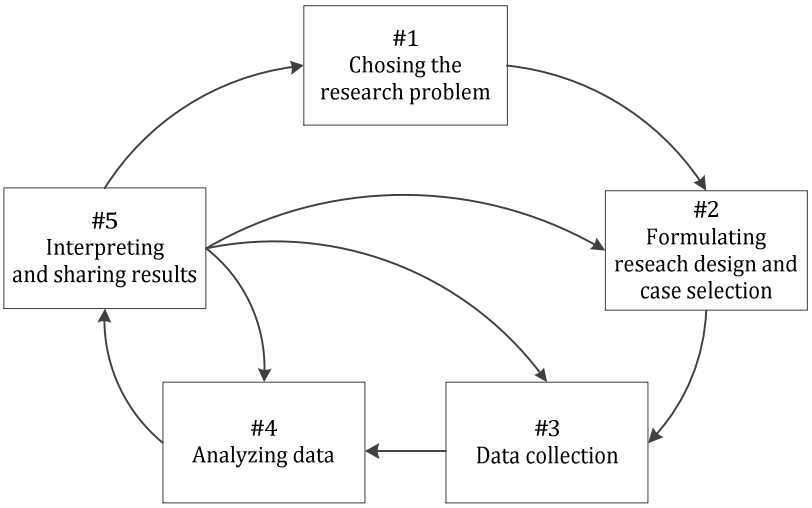

Figure 2: The research process (adapted from Yin, 2009 and Bailey, 1994)

3.1 Research design and case selection

An explorative case study was carried out in ALECTIA. Explorative case studies are appropriate when the objective is to generate an in-depth understanding of the complexity of a studied phenomenon in an organization (Thomas, 2011; Yin, 2009). The research was carried out as a single embedded case study, where focus was on both an overall case unit and to multiple sub-units embedded in the overall case unit (Yin, 2009). This framework was chosen, because my

interest in the studied phenomenon was two-sided: I wished to gain a better understanding of the possibilities and barriers for integrating ergonomic knowledge in design, both at ALECTIA's organizational level and at the project level. The embedded case units were constituted by three different design projects: The design of a sterile processing plant, the design of a hospital, and finally a conceptual design plan for a seafood company. According to Yin (2009), a common pitfall when choosing to conduct an embedded case study is that the researcher fails to return to the overall case unit. To avoid this pitfall, attention was given to the overall case unit in both article 3 and article 4, as well as in this overall thesis.

Case selection

Since the PhD project is an industrial PhD project funded partly by the ALECTIA-Foundation, the choice of ALECTIA as the case company was given. When reflecting upon ALECTIA as case company from a more strategic case selection point of view, ALECTIA can be seen as representing a 'typical example' of an engineering consultancy in Denmark with an internal ergonomic department or division (Yin, 2009). Although the generalizability of findings based on a single case study can be limited (Thomas, 2011), Yin (2009) argues that lessons learned on the basis of a typical case can be assumed to provide information about the experiences in similar cases.

The three embedded case units were chosen based on a combination of 'purposive sampling' (Miles & Huberman, 1994) and 'maximum variation' (Flyvbjerg, 2006). 'Purposive sampling' was used, because I was specifically interested in cases in which one or several ergonomists had been involved in the design process. 'Maximum variation' was used, because I wanted to obtain information on the possibilities and barriers involved in the integration processes across various settings and under different circumstances. The cases differed in a number of dimensions: business area of the client, type of design task, motivation for involving ergonomists, the number of ergonomists involved, way the ergonomists were involved, and the deliverances (both the ergonomic deliverances and deliverances of the entire design teams);
(see Table 1).

Table 1: Case characteristics (adapted, used originally in article 3)

PM= Project Manager, ED= Engineering Designer

Case characteristics	Hospital sterile processing plant	Seafood company	Hospital project
The design project	Detailed project proposal incl. layout and logistic	A conceptual design plan, including a master plan for one factory	A building project involving consultancy in all design phases.
Motivation for integrating ergonomics	The ergonomic department had been consulting the hospital for years. The hospital and the PM thought it would be a good idea to involve an ergonomist	The manager of the area consulting (see Figure 7) participated in the sales processes and sold the idea of integrating ergonomics	Ergonomics was addressed in the sales material for the architecture competition. This was an opening to integrate ergonomics in the project
Participants	Approx. 20 participants, including: - PM: an engineering designer - EDs with different backgrounds - An ergonomist	7 participants, including: - PM: an engineering designer - EDs with different backgrounds - An ergonomist	110 to 130 participants working together in a consortium consisting of: - Two architectural firms - Three engineering consultancies (incl. ergonomists) - Three sub-consultancies
Involvement of ergonomics	An ergonomist involved in part of the design process, through: - A visit to the future locations - Layout meetings - A project meeting	An ergonomist involved in the project through: - Trips to the client's factories - A meeting with providers - Various project meetings	Several ergonomists engaged throughout the design processes, through: - More than 400 user meetings - Responsible for design lab and full-scale mock-ups - Various project meetings - Continuous dialogues
Ergonomic deliverances	- An ergonomic guideline document to feed into the further design process - Recommendations included in the final layout sketch	- An individual ergonomic assessment report for each of the four factories - Inputs such as cost estimates and ergonomic assessments for the conceptual design report - Minor inputs for the master plan	- A room-specific database - A health and safety policy - An ergonomic requirement list, which due to resistance changed name to a recommendation list - An agreement that engineering designers and architects should seek ergonomic support if recommendations were hard to meet

3.2 Data collection methods

In this PhD dissertation, qualitative data collection methods were used. The rationale for choosing qualitative methods is similar to the rationale for choosing the case study design, namely that I wanted to gain an in-depth understanding of the studied phenomenon. The primary data source was interviews, supplemented by observations and document studies. Using a combination of different data sources allowed for a triangulation of findings. The data collection was carried out during the period between 2009 and 2012, interrupted by a maternity leave from June 2010 to February 2011 and a sick leave from October 2011 to April 2012. Table 2 displays the data collection methods used in the individual embedded case units and in the overall case unit.

Table 2: Data collection in the three embedded cases units and the overall case unit

	Hospital sterile processing plant	**Seafood company**	**Hospital project**	**The overall organization**
Data collection	- Interviews N=10 - Document study - Observation, to a minor degree	- Interviews N=3 - Observation - Document study, to a minor degree	- Interviews N=6 - Observation, to a minor degree - Document study, to a minor degree	- Interviews N = 8 - Observation - Document study, to a minor degree
Data collection period	Oct. 2009 to March 2010	Nov. 2009 to Jan. 2010	Oct. 2009 and May 2012 to July 2012	May 2009 to August 2012

Interviews

The purpose of doing an interview study is to gain insight into a studied phenomenon from the perspective of the interviewee's life-world, and to learn about their interpretations, opinions and actions in relation to the studied phenomenon (Kvale, 2004). In comparison with multiple-choice questionnaires with prefabricated questions and a limited number of answer possibilities, I find the interview form to be much stronger. Here, the interviewees can organize their own answers and descriptions, and emphasize what they find important. The interview focuses on central themes, and yet the interview form is open for following themes or perspectives that emerge during the interviews. The method is also able to capture ambiguities in the interviewees' viewpoints regarding the phenomenon being studied (Kvale, 1983).

A total number of 23 persons were interviewed in ALECTIA. Again, 'purposive sampling' was used to select the interviewees; the selection was information-oriented, rather than random. I was specifically interested in interviewing actors who had been involved in initiatives to integrate ergonomics in design to some extent. The interviewees selected were: CEOs (N = 2), ergonomists (N = 10) and engineering designers (N = 11). Furthermore, in the case of the sterile

processing plant, two interviews were carried out in the client organization, which involved two ergonomists, a health and safety representative and the manager of the sterile processing plant. These interviews were carried out to gain insights into how the initiatives to integrate ergonomics in design were received in the client organization, and whether or not ergonomic recommendations had been implemented. In both the overall case unit and in the three sub-units, engineering designers *and* ergonomist were interviewed to ensure a variety of perspectives.

The interviews were conducted as semi-structured interviews (Kvale, 2004). Prior to each interview, an interview guide was developed where the focus was on understanding different initiatives for integrating ergonomics into the engineering design practice, understanding the context of an initiative, and learning about different perspectives on possibilities and barriers for the integration. Table 3 presents a condensed version of the content in the interview guides. Due to the explorative nature of the study, however, the interview guides were mainly used as a supporting tool rather than being followed slavishly. In practice, I tried to follow up on the interviewees' answers in order to learn about new and unexpected viewpoints on the studied subject. Furthermore, the interview guides were adjusted throughout the study as new insights arose and different participants were interviewed.

Table 3: Focus points of the interview guides

- Understanding the context around a given initiative to integrate ergonomics in engineering design processes
- Reasons for introducing the initiative
- Content of the initiate
- How a given initiative had proceeded
- How the interviewee experienced possibilities and barriers of the initiative to integrate ergonomics in design

During the interviews, the interviewees referred to both incidents and aspects experienced in the engineering consultancy during design projects or thoughts they had on future projects. The interviews were all carried out face-to-face and varied in duration from 30 to 120 minutes. They were all audio-recorded, and all essential parts were transcribed. There were three exceptions: two where the informant did not wish to be audio-recorded, and one where no audio-recorder was available. During these interviews, thorough notes were taken during the interview, and immediately after the interview, more thorough interview reports were completed.

Observation

As a PhD candidate employed by ALECTIA, I spent approximately two working days per week at ALECTIA. This created an opportunity to supplement the interview data with observation.

In observation, the researcher seeks to look behind apparent expressions and try to discover underlying, socially regulated mechanisms (Kristiansen and Krogstrup, 2005). There are four main types of observation (see Figure 3).

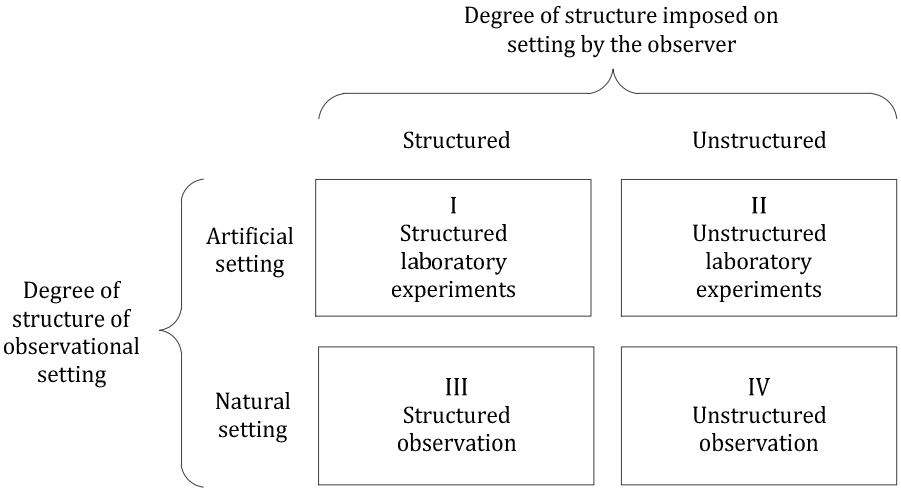

Figure 3: Types of observational studies (adapted from Bailey, 1994; Kristiansen and Krogstrup, 2005)

The observation made in ALECTIA was carried out in a natural setting where the experimental conditions were out of my control. It was a 'natural experiment', where the conditions changed during the course of the study – for instance when ALECTIA shifted from a matrix to a division-based organization. The observations can be characterized as structured, in the sense that I was only focusing on actions and interactions related to the integration of ergonomic knowledge in design. However, besides this, the observations can be characterized as unstructured (Type IV), since I did not follow a pre-developed observation guide. Gold (1970) distinguishes between four observer roles: complete participant, participant observer, observer participant, and complete observer. I mainly carried out observation in the overall case unit, and here I had the role of 'participant observer' (Gold (1970), in Kristiansen and Krogstrup, 2005). Kristiansen and Krogstrup (2005) characterize the role of a participant observer, as an observer that gathers data by participating in the daily life of the organization being studied. The participant observer observes how the members of the organization interact and by engaging in conversation with the members in the organization the observer learn how interactions are interpreted.

Overall case unit – During the first two years, I was both physically and organizationally part of an engineering department at the head office in Virum, where I had my own desk. The last year, I moved physically to a desk in one of the ergonomic departments, also in Virum, but I remained

organizationally a part of the engineering department. During the three years, I took field notes when I observed actions, events or talks specifically related to "the integration of ergonomic knowledge in design". At times, I also had to make practical choices about what to follow, as I otherwise would end up with too much data material. In the field notes, I wrote both descriptions of what I observed and my own thoughts about what I experienced.

Ethnographic interviews were also a part of the observation data (Kristiansen and Krogstrup 2005; Spradley, 1979). Ethnographic interviews have a lot in common with everyday conversations, but differ because the conversations have a specific purpose for the researcher, who gradually introduces ethnographic elements during the conversation. Some of the ethnographic interviews completed in this study were structured in accordance with Spradley's (1979) recommendations for ethnographic interviews (e.g. being explicit about purpose), while others had more the character of friendly conversations – for instance, when meeting people in the combined coffee and printer room. I also attended innumerable lunches, breakfasts, meetings and social events of different kinds; no notes were taken, but these experiences still contributed to my understanding of ALECTIA and possibilities and barriers for integrating ergonomics into the engineering design processes (Kristiansen and Krogstrup, 2005).

The embedded case units – When observing in the embedded case units, I had the role of an 'observer participant': My involvement was minimal and distant, and I was normally not a part of these social settings (Kristiansen and Krogstrup, 2005). A down side of observation of a relatively short duration is that it may be difficult to gain in-depth understanding of the social structures; there is therefore a risk that the subsequent analysis is superficial. I tried to counteract this risk by making interviews my primary data source, and by having more than one embedded case unit. The following is a brief account of the observation studies in each of the three embedded case units.

In the sterile processing plant, observation involved a visit to the completed sterile processing plant, where I could observe the design in operation. I observed the employees and interviewed four of them while they were working. The main goal of this visit was to identify whether or not the ergonomic recommendations had been realized in the implemented design.

In the seafood case, I had access to observe three design meetings that were held at ALECTIA's office in Odense. The aim of participating in these meetings was to learn what went on at design meetings and how issues around ergonomics were addressed. I took notes during the meetings; and at the end of each meeting, I asked questions if there was something I was uncertain about. On the trip back and forth to Odense, I received a lift from the project manager and an engineering designer. During these trips and at break times during the meetings, I

carried out ethnographic interviews to learn about the project and how ergonomics had been integrated into the project.

In the hospital case, I went to the design consortium's facilities in Aarhus for two visits to conduct interviews. On these visits, I had the opportunity to see the design lab and have lunch in the canteen.

Document study

A thorough document study was carried out in relation to the case of the sterile processing plant. This was the first case study I carried out, and the aim of the document study was twofold: 1) To learn more about how ergonomics was integrated into this design project and whether or not ergonomics was on the agenda at project meetings; and 2) to learn about how design projects in ALECTIA were carried out – e.g. the setup of the project, the progress of the design phases, and the kinds of documentation made in a design project. Hence, the document study involved examining minutes of meetings, project presentations, project plans, drawings, working documents, and finally an ergonomic guideline document. Based on these documents, I was able to create a flow chart displaying the progress of the design process on one of the walls in my office. This visual method was very useful in creating an overview and learning about the progress of the design project (see Figure 4).

Figure 4: Illustration of the flow chart

3.3 Data analysis methods

In the data analysis process, a combined inductive and deductive approach was used. I used a combination of the two approaches, because I found both approaches rather appealing and thought that both approaches could contribute valuable insights into the studied phenomenon. The inductive analysis approach appealed to me because this approach allows findings to emerge from data; thus, the findings derived from using an inductive approach are grounded within the data. The appealing aspect of the deductive approach, on the other hand, is that a theoretical lens can guide you to valuable insights that might not have emerged using an inductive approach.

The theoretical framework for the dissertation is accounted for in chapter 4, while the theoretical perspectives used during the deductive analysis approach in article 2 and article 4 are accounted for in the individual articles. Table 4 below shows which approach was used in each article.

Table 4: Analysis approach used for the different articles

	Article 1	**Article 2**	**Article 3**	**Article 4**
Analysis approach	Inductive approach	Combining the inductive and deductive approach	Inductive approach	Deductive approach
Data material	The case of the sterile processing plant: Interviews, observation and document study	The case of the sterile processing plant: Interviews, observation and document study	The embedded case study: Interviews, observation and document study	The embedded case study: Interviews and observation

Inductive analysis approach

The inductive approach used in this PhD study is primarily based on Thomas (2006). The overall goal of the inductive approach put forward by Thomas (2006) is to allow findings to emerge from data by searching for dominating or significant themes relevant to the research objectives. Hence, the goal is to let underlying structures of experiences and processes emerge from data. According to Thomas (2006), the findings can be presented either as a model, a framework, or a description of the most important themes. The coding process is based on multiple readings of the data material and guided by the research objectives. Table 5 presents the steps of the inductive coding process presented by Thomas (2006).

The inductive approach was also inspired by readings on grounded theory. During coding processes, I used the "constant comparative method" (Glaser and Strauss, 1967, pp. 101-115), where text segments presenting different perspectives, actions, events or interactions are constantly compared and contrasted to let categories emerge from data. I was also inspired by

Corbin and Strauss's (1990) technique of posing different questions to the data material, as a means of staying open to emerging themes.

Table 5: The coding process in inductive analysis (adapted from Thomas 2006, p.242)

Initial reading of text data	Identify specific text segments related to objectives	Label the segments of text to create categories	Reduce overlap and redundancy among the categories	Create a model incorporating most important categories
Many pages of text	Many segments of text	30-40 categories	15-20 categories	3-8 categories

More thorough descriptions of the both the inductive and the deductive analysis processes are included in each of the articles.

3.4 Interpreting and sharing results

When doing qualitative studies, interpreting and sharing finding is an integrated part of the analysis process and can be used as a way of counteracting potentially biased interpretations (see Figure 2). In this PhD study, I have sought to enhance the validity of my results primarily through 'research community', triangulation of data collection methods, and 'members check' (Kristiansen and Krogstrup, 2005; Kvale, 2004). While the data collection methods have previously been accounted for, this section briefly addresses the validation activities in 'research community' and 'members check'.

Research community – Throughout the research process, and particularly during the analysis processes, my supervisor, Ole Broberg, played an important role by giving critical responses regarding emerging categories, preliminary findings, and interpretations. In order to counteract biased interpretations, he questioned the findings, suggested alternative explanations etc. Hence, the dialogues and discussion with him inspired new ways of seeing the data material. Analysis activities were also carried out during my external research stay at Ryerson University in Toronto. During this period, I received great support and inspiration from dialogues and discussion with Patrick Neumann and a small group of researchers around him, who were all engaged in qualitative analysis. We met once a week in this 'qualitative group' and shared both frustrations and findings. This helped me a lot, especially when at times I found myself experiencing 'analysis paralysis'. Through feedback and discussions, I found my way through the process, and this helped to counteract bias.

Members check - My co-supervisor, Lars D. Christoffersen, played an important role in relation to 'members check', as he was also employed in ALECTIA. In continuous dialogues and discussions with him, he continuously offered me feedback on my preliminary findings and

interpretations, and contributed with alternative or additional explanations. Throughout the research process, I also sought to validate my preliminary findings and interpretations by including them in subsequent interviews so that the interviewees could comment or correct me. Finally, I also presented my preliminary findings to different employees in ALECTIA. I received valuable feedback during these sessions.

3.5 Methodological reflections

The risk of going native

As an industrial PhD candidate, I was part of the organization I was studying. While this gave me many advantages like 'access to the field', it was also challenging at times. For anyone engaging in qualitative studies where observation in a natural setting is one of the data collection methods, there is a risk of going native. The researcher starts to internalize the field's ways of thinking and becomes an integrated part of the field. This risk is obviously even greater when doing observational studies in your own organization. In ALECTIA, I was not only a researcher, but also an employee and colleague.

While 'going native' can have some positive effects, such as a more authentic experience of the context studied and gaining access to more intimate and hidden details of the field, there are also negative effects, such as bias and difficulties maintaining an analytical distance (Kristiansen and Krogstrup, 2005). To handle this risk of going native, Simmel (1972) introduces a distinction between 'closeness' and 'distance', and argues that the researcher should assume the role of a 'stranger' (Simmel (1972) in Kristiansen and Krogstrup, 2005). Although it was impossible for me to assume the role of a stranger, these concepts were a rather useful 'reflection tool' for me. They helped me maintain some distance to the field. In practice, I used DTU has my second 'home', especially during analysis and writing periods when I found it useful to maintain some distance to the field in order to reduce potential bias. According to Steffan (1995), however, experience and reflection are not a question of either/or; she argues, that they can be combined, and while it might be possible to momentarily slide out of the role of researcher, it will never be totally suppressed (Steffan (1995) in Kristiansen and Krogstrup, 2005). These reflections by Steffan (1995) were a great comfort to me, when I sometimes allowed myself to let go of the researcher role and be 'just an employee going to work' at ALECTIA. Some reflections on interview situations are to be found in article 2 and article 3.

Generalizability

It has often been argued that results based on case studies, and particularly single case studies, are not generalizable. While without doubt single cases studies are not statistically generalizable, different authors have contributed with valuable viewpoints on both the value of

case studies and how they can be used for generalization. Flyvbjerg (2006) argues that "formal generalization is overvalued as a source of scientific development, whereas 'the force of example' is underestimated" (Flyvbjerg, 2006, p. 228). Furthermore, Flyvbjerg (2006) argues that concrete and context-dependent knowledge is more valuable than the search for predictive theories and universals.

According to Flyvbjerg (2006) the generalizability of case studies can be increased by strategically selecting the cases to be studied. In connection with my earlier reflections concerning ALECTIA as a 'typical example' of an engineering consultancy in Denmark with an internal ergonomic department or division, Yin (2009) argues that lessons learned based on a typical case can be assumed to provide information about what is experienced in similar cases. Hence, while the findings based on this PhD project are specifically linked to ALECTIA, they can also be expected to provide guiding information on similar settings.

4 Theoretical framework

Throughout this PhD study, a combination of different theoretical perspectives was used to shed light on the possibilities and challenges of integrating ergonomic knowledge in design processes in the engineering consultancy setting. The theoretical lenses are constituted by concepts derived from three main theoretical traditions associated with *Science and Technology Studies* (STS) and theoretical perspectives on *learning* and *knowledge management*. In prior studies undertaken to shed light on the problems connected with integrating ergonomics in design, the theoretical lenses chosen have only seldom been used.

4.1 Science and Technologies Studies

The STS tradition can be described as multiple and interdisciplinary. As a whole, the tradition shares a common interest in science, technology and society, and has especially been drawn to opening "the black box of technology" in order to understand the processes through which technology is constructed (Jensen et al., 2007; Latour, 1987). In the attempts to contribute nuanced understandings of the patterns in the complex processes through which the reality of technology is shaped, the STS tradition focuses on both humane actors and non-humane actors – e.g. objects like documents, tools, web-based knowledge repositories or physical surroundings. In analysis activities, the tradition diverges from more traditional linear understandings of processes and cause-effect relationships (Gherardi and Nicolini, 2000; Jensen et al., 2007; Vinck and Jeantet, 1995). This PhD study has been particularly inspired by the dual focus on human and non-human actors offered by this tradition, and I believe that this focus can lead to new understandings of possibilities and barriers related to integrating ergonomic knowledge and design.

Objects

In engineering design, actors are surrounded by objects of different character. The role of such objects in design has been examined in a number of studies (e.g. Boujut and Blanco, 2003; Carlile, 2002, 2004; Vinck and Jeantet, 1995). So far, however, only a few studies in the HF literature have been inspired by elements from the STS tradition, and only minor attention has been given to the role of objects in integrating ergonomic knowledge in design (Broberg, 2007; Broberg et al., 2011; Conceição et al., 2012).

In engineering design, the traditional view of objects, such as drawings and prototypes, is to see them as neutral commissioning objects: The objects are a means to come from an idea or a goal to a result (Vinck and Jeantet, 1995). From an STS point of view, objects and humans are inextricably linked throughout design processes. Objects are regarded as mediators where

objects, as well as the users of a given object, can play an active role. Objects are active in the sense that they do not represent the full diversity of mental images or ideas for the workspace being designed, but rather specify certain aspects of a design and leave out other elements; once completed, an object creates constraints on the further design process, since it limits possibilities for action. Hence, objects are mediators and "affect the interplay, just like actors" (Vinck and Jeantet, 1995, p. 303). The users of an object are however not completely trapped by the object. Any given object also holds some degree of interpretative flexibility, which means that there is always "some degree of freedom in terms of use" (Vinck and Jeantet, 1995, p. 305).

In article 2, I draw upon two different theoretical concepts derived from the STS tradition, namely b*oundary objects* and *intermediary objects.* Here, I make a distinction between *boundary objects* that function as mediators in the direct communication between actors, and *intermediary objects* used as a means of transferring and sustaining knowledge over a distance. For more on this, see article 2.

4.2 Managing knowledge and learning processes

In knowledge intensive organizations like ALECTIA, the entire staff can be characterized as knowledge workers (Newell et al., 2002). When the entire revenue is based on consulting, it becomes strategically important to be able to manage the employees, but managing knowledge workers is not an easy task (Garud and Kumaraswamy, 2005; Newell et al., 2002). In general, knowledge workers expect and demand a great deal of autonomy, which makes it hard to control and manage knowledge work processes. Both Newell (2002) and Garud and Kumaraswamy (2005) have a processual understanding of knowledge. They see knowledge as being embedded in social relations and contexts, where people, structures, tools and processes are interwoven through complex dynamics.

Following a one-sided approach to knowledge management can be rather risky, because opposing forces often exist at and across different levels in an organization. When striving to stimulate a particular practice through one type of initiative, parallel and unintended knowledge processes will often exist or emerge in other parts of the organization, because individual actors influence the processes in the direction that corresponds to their own particular interests. Hence, managing knowledge processes calls for different approaches and initiatives in order to facilitate the emergence of virtuous learning circles and be able to steer out of undesired circles (Garud and Kumaraswamy, 2005; Newell et al., 2002; Senge, 1990).

Newell et al. (2002) stress the importance of managing knowledge for a purpose. Knowledge per se has no value unless it is created and applied for a specific purpose. Likewise, knowledge management only generates value to the extent that it actually accommodates a purpose that contributes to some kind of organizational advantage. Hence, the role of knowledge management is to introduce mechanisms and strategies that can facilitate and coordinate the knowledge processes that need to be integrated in order to fulfill a given purpose. Attempts to manage knowledge processes should be sensitive to the cultural and social context, as well as the structural conditions in an organization (Newell et al., 2002; Garud and Kumaraswamy, 2005).

Working across different knowledge domains

Integrating ergonomic knowledge into engineering design processes implies initiating a process of innovating work processes across different knowledge domains. The theoretical lens of 'community of practices' (Wenger, 2000) offers a way of understanding epistemic challenges of working across different knowledge domains. The notion of communities of practice was developed by Lave and Wenger as a part of their work on situated learning and legitimate peripheral participation (Lave and Wenger, 1991). According to Wegner (2000), organizations can be understood as constellations of different communities of practices, each of them connected through a shared practice.

Brown and Duguid (2001) find that knowledge tends to leak in the direction of a shared practice, while it tends to stick when no shared practice exists. This relation can largely be explained by the 'social-epistemic bond' that is created through engaging in a shared practice. Challenges of working across different practices can be related to "people with different practice have different assumptions, different outlooks, different interpretations of the world around them and different ways of making sense of their encounters" (Brown and Duguid, 2001, p. 207). Carlile (2002, 2004) argues that the challenges of working across boundaries go beyond knowledge being *located* within practices. He argues that knowledge is also *invested* in practices, in terms of the time and resources needed to acquire and maintain a certain knowledge base (Carlile, 2002, 2004). Hence, when engaged in practice, knowledge is *at stake* for the individual actors, and as a consequence, there is often a reluctance to alter knowledge and skills. Elements of power can become an issue when working across knowledge boundaries – for instance, if one actor group has a greater power base than other groups (Carlile, 2002, 2004).

Based on studies of engineering design, Bucciarelli (1994) also addresses the epistemic differences between knowledge domains, and introduces the term 'object worlds', which refers to different knowledge domains with different ways of seeing the design *object* in question. As

described in chapter 1, Bucciarelli (1994) contributes an understanding of engineering design as a social process of negotiations and tradeoffs between actors from different object worlds. Hence, managing engineering design processes requires initiatives to establish a common language that makes it possible for design actors to address problems on a common ground and to reach some degree of consensus.

Brown and Duguid (2001) point out that elements of motivation and trust are important factors in facilitating work processes across practice domains. The literature about communities of practice also suggests that other central elements are important in facilitating cross-disciplinary work processes. These are:

- *brokering*, where for instance an actor, who is engaged in several practices functions as mediator between practices;
- *boundary objects,* here defined as objects that "… support connections between different practices" (Wenger, 2000, p. 236);
- *boundary interactions* such as visits or discussions between practices;
- *cross-disciplinary projects*.

4.3 Reflecting on choice of theoretical perspectives

In consultancy companies, knowledge plays an important role in the products that are delivered to clients. The theoretical perspectives chosen all contribute with a focus on how knowledge is generated and shared between actors. The theoretical concept of objects derived from the STS tradition can contribute with new insights on the role of objects when integrating ergonomic knowledge in design, and help create new understanding about how objects in different situations can either facilitate or limit knowledge sharing across different knowledge domains. The chosen theoretical perspective on learning contributes an understanding of the challenges of working across different knowledge domains; it also emphasizes that meetings between practices embrace great learning opportunities. The chosen perspective on knowledge management can also contribute ideas about how to stimulate and facilitate the development of a new combined practice around integrating ergonomic knowledge in design, while Carlile (2002, 2004) contributes a perspective on how the interactions between different actors in an organization are also affected by elements of politics and power.

A different choice of theoretical perspectives would most certainly have guided me to other findings and recommendations. Other interesting theoretical choices could have been perspectives such as change management or a cultural or political process perspective. A theoretical choice of the political process perspective would have focused on decision-making and change processes around integrating ergonomic knowledge in design, and would have pointed to insights regarding how different actors form coalitions in order to promote their own interests in organizational settings.

5 Case company

ALECTIA A/S is a consulting company that provides consulting services within the following business areas: services, manufacturing, universities, local government, investors, utilities, hospitals, pharmaceuticals, breweries, dairy and food. ALECTIA was established in 1912 under the name Birch & Krogboe, which was changed in 2008 to ALECTIA. The headquarters is located in Virum, Denmark. ALECTIA also has three other locations in Denmark and one location in London, UK. The company is owned by the ALECTIA Foundation and has about 700 full-time employees. ALECTIA operates mainly on the Danish market where the main competitors are NIRAS, COWI, Grontmij, Rambøll, and Orbicon, and in the area of ergonomics also CRECEA. ALECTIA's proclaimed strategy, vision and mission is displayed in Figure 5.

Strategy

ALECTIA – Masterminding sustainable progress

Vision

Mastermind sustainable progress to ensure continuous value creation by our clients

Mission

We will achieve our vision through cross-disciplinary collaboration, business-driven sustainable solutions and vertical market approach

Figure 5: ALECTIA's strategy, vision and mission statements (from ALECTIAs intranet)

ALECTIA can be characterized as a knowledge-intensive firm (Newell et al., 2002), where the entire revenue is based on consulting, solving problems and providing solutions for clients. Until 2005, the company was a traditional engineering consultancy, but during the years 2005-2011, the company made eleven strategic acquisitions, three of which were ergonomic consultancies. The first two ergonomic consultancies were acquired during 2006-2007, while the third was acquired in 2011. In this study, the focus is specifically on the ergonomic consultancies acquired during 2006-2007, which at the time of acquisition employed approximately 105 OHS consultants. The acquisitions were part of a newly developed growth and differentiation strategy: The CEO and board of directors wanted a greater variety of competencies with which to access the market; both in terms of stand-alone services and as combined services, which would hopefully lead to a competitive advantage for ALECTIA in terms of high quality solutions. Here, it is the combined services that are of interest, namely the integration of the newly acquired ergonomic competencies into engineering design projects.

Today, ALECTIA has 77 ergonomists employed across the four Danish offices, and it can be characterized as a consultancy firm with a broader line of services that include ergonomics, logistics, and a range of engineering disciplines related for instance to building, production and

environmental issues. The typical phases of design projects carried out by ALECTIA are illustrated in Figure 6. In practice, the content and phases of the design projects vary, depending for instance on the business area of the client and the scope of the design task. Hence, some design projects follow the phases as described in Figure 6, while others may only involve, for instance, the first three design phases.

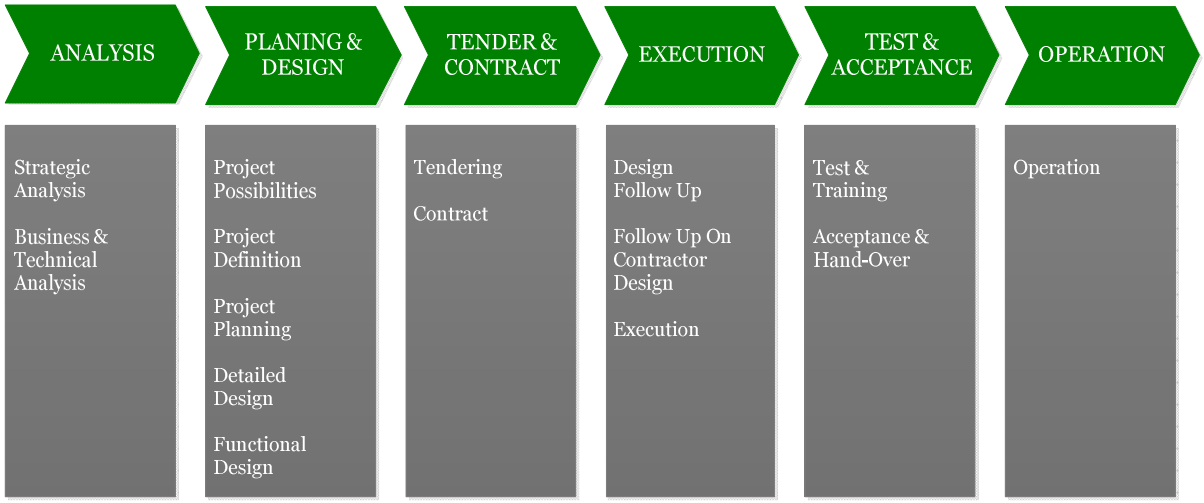

Figure 6: ALECTIA's delivery model - illustrates typical phases in design projects carried out in ALECTIA (adapted from ALECTIA's intranet)

5.1 Organization and development

During this PhD study ALECTIA A/S has had three different CEO's and undergone one major organizational change. When the PhD project was initiated ALECTIA was organized in a matrix structure (see Figure 7).

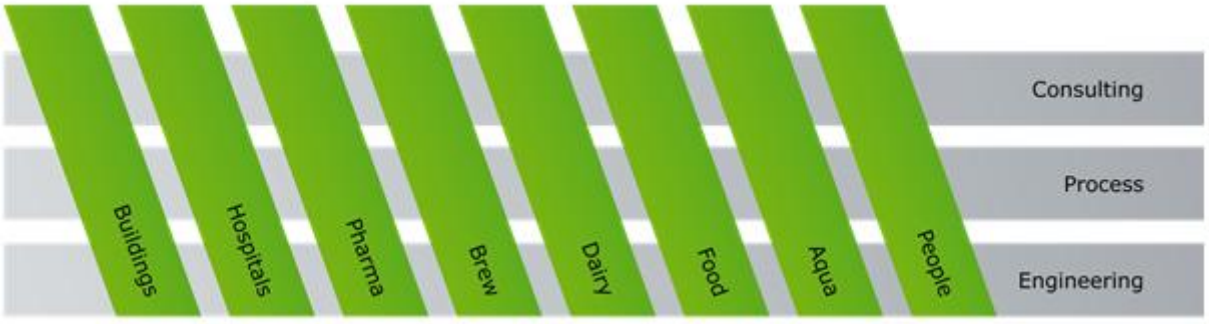

Figure 7: Matrix structure in ALECTIA from 2005 to 2011 (from ALECTIAs intranet)

This matrix structure was introduced shortly before the acquisitions of the OHS consultancies. The aim of the matrix structure was to support the company's differentiation strategy and generate an overview of the main business areas ALECTIA operated within. Hence the structure consisted of three competence areas and a number of business areas, see Figure

7, where the competence areas are illustrated in horizontal boxes and the business areas in vertical boxes. Organizationally the ergonomists were placed in ergonomic departments within their own competence area, 'Consulting' (see Figure 7). To smooth the transition period an ergonomic business area called People was also establish. During this transition period the ergonomic department continued to use their own IT systems for project and financial management. Physically, the ergonomists were placed in 'OHS department spaces' in the engineering consultancy's offices. In 2009, the business area People was removed and the ergonomists then provided their services to the same business areas as the rest of the company.

During the years from the 2006 to 2011 different initiatives to support the development of a combined practice were launched at a corporate level (see Table 6). In this period, activities aimed at integrating ergonomics in design also started to emerge at other levels of the organization, mainly on the initiative of individual actors, who saw the potentials of integrating ergonomic knowledge in design.

Table 6: Main initiatives launched to support cross-disciplinary work (adapted on the basis of article 4)

Initiative	Explanation
New strategy and vision/mission statement	Focus on cross-disciplinary work and sustainability
Matrix organization	Integrate the ergonomists into the existing matrix organization.
Staffing process	A formal staffing process with appointed staffing coordinators was introduced for all projects above ½mill DKK. The aim was to stem informal staffing processes and to make sure that all relevant competence areas were represented in the project group.
Competence wheel	An illustrative "competence wheel" was launched to highlight the main competence areas in the company. To the extent possible all competencies should be brought into action in design projects.
Delivery model	A delivery model was launched on the company's intranet. The purpose was to uniform processes, create a common frame of reference and establish a knowledge repository, where employees could learn about what other knowledge domains could contribute in different design phases.
11 o'clock news	The company's daily 11 o'clock news update was used actively to promote cross-disciplinary work by reporting on successful cross-disciplinary projects.
Integrated design process	A uniform approach to design called "integrated design" was launched. The language used in this framework corresponded to the vision of the CEO and a the engineering designers were already using this approach.
Slogans like "Dare to advise"	The slogan "dare to advise" was often articulated. The aim was: "Make the client demand what *we* believe is the right solution". This slogan was based on client satisfaction surveys in which clients acknowledged ALECTIA stepping into the counselor role instead of simply carrying out clients' requests.
Linking marketing managers	The OHS marketing manager was physically placed next to the engineering marketing managers with the aim to promote the sale of combined services.

During the period from 2009 to 2011, the company started to experience the effects of the global financial crisis. After a number of good years income-wise, the company now experienced minor deficits, and in April 2011, a new CEO was appointed. To create greater transparency in relation to the company's profit performance, a new division-based organization was introduced in January 2012(see Figure 8).

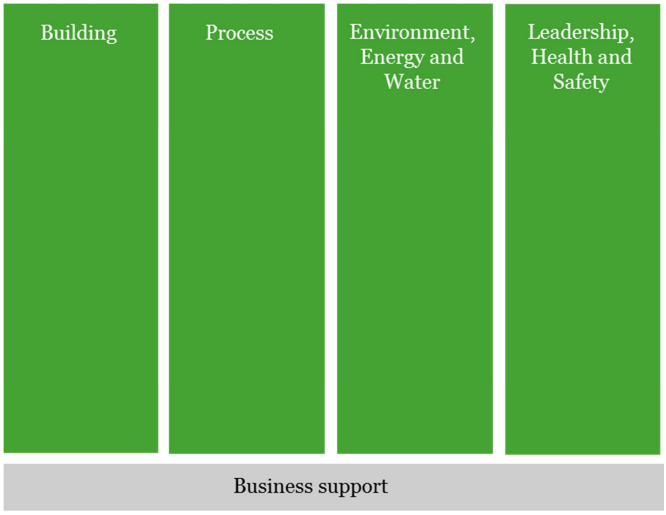

Figure 8 ALECTIA Organization anno 2012 (from ALECTIA's intranet)

The new division based organization was also introduced to decentralize decision-making processes and to enabling employees to act faster in the market. Each division was established as a profit center, where the manager of each division now was responsible for both budgets, invoicing degree etc.

In the new division-based structure, the ergonomists were placed in their own division, called Leadership, Health and Safety. They were now separated – organizationally, physically and profit-wise – from the engineering designers. After the new CEO entered the company in 2011, the rhetoric about integrating ergonomic knowledge in design was toned down, and no new initiatives to promote integration were introduced. A shift in the strategic focus in the company was also identified. The overall differentiation strategy stopped being articulated as often, and strategies were now formed locally in each division, where the main goal was to generate profit within each division. As a consequence, the initiative to link the marketing managers was also dropped (see Table 6).

The case description sets the stage for the next chapters were the findings of this PhD study is presented and discussed. The following sections provide short presentations of ALECTIA's PhD program and the three embedded case studied.

5.2 ALECTIA's PhD program

ALECTIA is owned by the ALECTIA-Foundation, which seeks to strengthen the visibility of ALECTIA. The overall objective of the foundation is "to benefit the further education and development of Danish engineers as well as to strengthen the reputation of Danish engineering activities in Denmark and abroad" (ALECTIA, 2013). As part of this objective, the ALECTIA-

Foundation has established a PhD program to be carried out in ALECTIA. The intention is to have an average of four industrial PhD projects running concurrently. The PhD program is given high priority, both by the foundation and in ALECTIA, because it helps to connect ALECTIA to research and education environments and supports "development of ALECTIA as a knowledge-based company" (ALECTIA, 2013).

5.3 Case description of the three design cases

Here, I include short descriptions of the three embedded case units mentioned in the method section. For further details, see Table 1 and the individual articles.

Design of a sterile processing plant

In 2008, the engineering consultancy firm was hired to execute the logistics and layout of a new sterile processing plant. Due to lack of space in the areas designated for the sterile processing plant, an ergonomist was assigned to participate in the design task. When the ergonomist entered the design process, the design team had already carried out user meetings, conducted a capacity analysis, and made a preliminary outline for the logistics and flow of the plant. The first layout sketches had also been made. The main task of the ergonomist was to complete an ergonomic guideline document stating her recommendations for the sterile processing plant. In order to be able to do this, she was invited to pay a visit to the future location and speak to some future users of the sterile processing plant. The ergonomist also participated in a few internal project meetings and had a couple of design meetings with an engineering designer and the project manager, where they discussed the layout of the sterile processing plant based on the layout sketches that had been developed. Hereafter, she completed the OHS guideline document and left the project. The rest of the design team concluded their work shortly thereafter, when the project proposal summing up their design solutions was delivered. In the construction and implementation phases, the hospital also received assistance from an engineering designer from ALECTIA.

Conceptual design job for a seafood company

In 2009, the engineering consultancy was hired to make a conceptual design plan for a Norwegian seafood company. The conceptual design plan consisted in mapping and analyzing four of the company factories for the purpose of creating different scenarios for the future development of the company. The design team was also to complete a master plan for one of the company's factories. An ergonomist was involved in the project, because the manager of the competence area, 'Consulting', had participated in the sales process and managed to sell

ergonomics as an additional service. As a consequence, an ergonomist was involved throughout the project, which lasted approximately three months

To carry out the analysis necessary to complete the conceptual design plan, the entire design team (see Table 1) spent between two and one-half to four days in each of the four factories. During these visits, the domain-specific analyses were carried out separately, and once in a while the team would meet in a shared office and discuss their findings. After the visits to the factories were completed, the work processes of the ergonomists and the rest of the design team were mostly carried out separately, supported by three joint meetings. The project was concluded when a conceptual design report was delivered to the seafood company. The ergonomic aspects in this report were included in separate sections. Each of the four factories also received an ergonomic assessment report.

Design of a hospital

The third embedded case study revolved around the design of a large hospital in Denmark. ALECTIA was part of a large design consortium that was selected in 2007 to execute the design. The consortium consisted of two architectural firms, three engineering consultancy firms, and three sub-consultants. Approximately 20 percent of the employees in the consortium were employed in ALECTIA. Ergonomists from ALECTIA were also involved, since ergonomics had been a focal point in the sales material provided by the client.

To start with, ergonomics was only involved in the preliminary phase of the project. In this phase, two ergonomists from the engineering consultancy were assigned to the design task. They developed a room-specific database that was aimed at providing ergonomic information to the engineering designers and architects involved in the project. At the end of 2009, it was decided that only locally employed consultants should participate in the project; hence, the two ergonomists were replaced by some of AELCTIA's ergonomists employed in the local area. Around this period, the area of ergonomics went from being part of a sub-project, which also covered environmental aspects, to being a sub-project on its own with an earmarked budget.

6 Findings

The main findings of this PhD project are presented in four articles. In each of the four articles, I have explored different aspects of integrating ergonomic knowledge into design, and each of them contribute to a nuanced picture of the possibilities and barriers in relation to integrating ergonomic knowledge into design. Here, I offer a short summary of each article; the articles are included in appendixes.

6.1 Article 1

Integrating ergonomics in design processes: a case study within an engineering consultancy firm
(Published in *Work*, vol. 41, 2012, pp. 949-955)

Empirically, this article draws on the case of the sterile processing plant. Based on an inductive approach, the article explores the premises for integrating ergonomic knowledge into an engineering design process and can be seen as a preliminary screening of factors that constitute either promoters or barriers for integration initiatives. A model was developed illustrating the different factors that emerged during the coding process. The paper concludes by presenting the identified promoting factors as well as potential promoting factors.

Implications

Different implications are suggested for engineering consultancies, ergonomists and design projects.

Table 7: Implications derived from article 2 (ED = Engineering Designer)

Engineering consultancies	Design Project	Ergonomists
- Formalize preliminary meetings between ED and ergonomist when new projects enter the organization - Introduce cross-disciplinary forums for knowledge sharing between ergonomists and EDs - Team up in sales - Discuss internally how to handle the 'extra costs' of involving ergonomists in design	- Involve ergonomists throughout the design project (in one way or another) to ensure that ergonomic support is given when design criteria conflict - Consider the use of artifacts to facilitate knowledge sharing	- Establish positive relationships with EDs in order to sell ergonomic services - Learn terminology and phases of design practice

6.2 Article 2

Integrating ergonomics into engineering design: The role of objects
(*Applied Ergonomics*, revision)

Based on the case of the sterile processing plant, this article explores how objects play a role when integrating ergonomic knowledge into an engineering design project. Based on the two theoretical concepts, *boundary objects* and *intermediary objects,* the article illuminates, how objects can constitute either a facilitator or a barrier when integrating ergonomics in design.

The findings show that layout sketches, in the role of boundary object, helped facilitate collaboration between an ergonomist and engineering designers. The ergonomist was only involved in the design project for a limited period, but before she left the project, she completed an ergonomic guideline document. In the role of intermediary object, the ergonomic guideline document meant to transfer ergonomic knowledge to downstream actors in the design process. It turned out, however, that the document was not able to fully achieve a distant effect in the further design process. In the meeting with downstream actors, some of the guidelines were transferred to the final design of the sterile processing plant, while others were transformed. The study also shows that throughout a design process an object can play different roles – both as a boundary object in the direct communication between actors; and as an intermediary object, where the aim is to transfer knowledge over a distance.

Implications

This study suggests that more attention should be given to the role of objects when integrating ergonomic knowledge into engineering design projects. Both engineering designers and ergonomists should carefully consider how different objects can help integrate ergonomic knowledge in design, and what their potential limitations might be. Boundary objects that can facilitate 'on-the-spot' visualization of different design solutions are especially good at supporting dialogues between ergonomists and engineering designers. When using intermediary objects as a means to transfer ergonomic knowledge, ergonomists and engineering designers need to look ahead in the design process and consider what kind of obstacles an intermediary object might meet on its way and plan how for supporting organizational initiatives – for example, an arrangement where ergonomists are contacted if conflicts arise between different design criteria.

6.3 Article 3

Integrating ergonomics knowledge into business-driven design projects: The shaping of resource constraints

(*International Journal of Industrial Ergonomics*, submitted)

This article was based on an inductive method where the entire data material was analyzed. Based on this analysis, I found that resources were shaped as constraints for the integration of ergonomic knowledge into engineering design projects in ALECTIA. This article addresses how these resource constraints were shaped and how ergonomists coped with the experienced resource constraints.

The resource constraints were shaped by such mechanisms as a constant focus on maximizing project revenues, challenges related to payment for ergonomic services, and a lack of cost benefit accountability of the ergonomic services. I found that an almost impermeable division between design and operation costs led to a sub-optimization of resources during design. This sub-optimization of resources clashed with the value of integrating ergonomics in design, which should be evaluated based on the full life cycle of the designed work system across design and operation phases. While some organizational initiatives were launched to promote the integration, I found that in practice the ability to overcome the constrained resources rested largely upon the individual ergonomist and his/her ability to act and develop strategies in integration processes. The ergonomic ambitions of the individual client played a major role for the possibilities to integrate the ergonomic skills in design projects.

Implications

The article contributes to an increased understanding of possibilities and barriers for integrating ergonomic skills in a business-driven design setting. The implications are directed at engineering consultancies and ergonomists wishing to promote the integration:

- Pursue the ergonomic ambitions of clients, for instance by teaming up engineering designers and ergonomists with sales
- Provide ergonomic training for engineering designers to enable them to address ergonomic issues in dialogues with clients, and offer "engineering design training" to ergonomists to enhance their ability to act in design processes.
- Develop 'standardized ergonomic design services' that link up with engineering design processes, as this can reduce the cost of integrating ergonomics in design.
- Include ergonomics as a strategic goal in the engineering consultancy, and establish initiatives to implement the strategy, for instance by including 'selling ergonomic services' as a goal in the performance measurement system.

6.4 Article 4

Learning opportunities across knowledge domains
(*Journal of Workplace Learning*, submitted)

This article is based on the observations and interviews carried out internally in ALECTIA. The article focuses on learning opportunities and challenges when introducing the newly acquired ergonomic competencies into the existing engineering design practice in ALECTIA. The analysis was based on a combination of different theoretical perspectives such as 'communities of practice', 'object worlds' and perspectives on knowledge management.

The findings are presented through three illustrative vignettes, and a special focus on is also given to top-down initiatives introduced at corporate level. It was found that while learning did occur, it remained discrete in pockets of learning, mainly at the individual level or project level, or as domain-specific learning. Learning opportunities arose in the meeting between engineering designers and ergonomists particularly when ergonomists became involved in engineering design projects. Learning that resulted in a *transformed* practice was identified when ergonomists reflected upon different approaches for integrating ergonomics in design and acted on the basis of a new approach.

Learning opportunities were hindered by elements such as domain-specific interests, power, managerial support, structural conditions and epistemic differences between knowledge domains. Top-down initiatives launched to institutionalize new cross-disciplinary routines were never fully implemented in practice, because undesired learning cycles strove to maintain the existing engineering design practice.

Implications

I argue that managing knowledge processes across the knowledge boundary between engineering designers and ergonomists requires attention to the *complexity* of the boundary between them *and* an effort to identify the underlying drives of undesired learning circles.

Furthermore, the development of a new practice needs a common strategic focus with the aim of developing cross-disciplinarity to guide the development process. In addition, the development needs various forms of supporting initiatives, such as brokering launched at different levels of the organization, and feedback loops that can capture learning experiences and couple them to other organizational levels. Managing knowledge processes also requires constantly monitoring launched initiatives, and a readiness to change, alter, or counteract when undesired learning loops arise.

7 Contributions and discussion

In this chapter, I answer the overall research question by focusing on each of the three sub-questions. I look across the four articles and draw in additional empirical findings when they can contribute to enrich or help further elaborate the answers. The findings related to each of the sub-questions are presented as aggregated findings, which are elaborated and discussed in relation to the HF literature and the theoretical framework.

7.1 Constraints to integrating ergonomic knowledge in design

Despite the large number of ergonomists present in the engineering consultancy, the integration of ergonomics in the engineering design processes only happened discreetly in some of the design projects. A new institutionalized practice around integrating ergonomics in design was not identified. The first sub-question focuses on the constraints to integrating ergonomics in design in an engineering consultancy:

Why is ergonomic knowledge not or only partly integrated in engineering design projects in the setting of an engineering consultancy?

Figure 9 presents the main barriers that were identified. They are elaborated and discussed in the following sections.

1) **Resources are shaped as constraints in a business-driven design setting**
2) **Epistemic differences, domain-specific interests and uneven balance of power limit integration**
3) **Objects used as means of transferring ergonomic knowledge over a distance face difficulties in creating a distant effect**
4) **A traditional ergonomic approach can limit integration in a business-driven design setting**
5) **Lacking organizational initiatives and organizational structure to support integration**

Figure 9: Main barriers of integrating ergonomics in design in the engineering consultancy

1) Resources are shaped as constraints in a business-driven design setting

In engineering consultancies, design projects are completed in client-consultant settings and can be characterized as being business-driven: The consultancies engage in design to provide a service for a client *and* to generate a profit through the design activities. In this business-driven

design context, I found that resources were shaped as constraints for integrating ergonomics in design. Both prior to contract formation and once a project was initiated, the main focus was to minimize the amount of consultant hours spent on a project in order to maximize the revenue from project. This focus was reinforced in the company's performance measurement system, where the focal points 'profit of the individual projects' and 'employees' invoicing degree' were dominant.

It is widely recognized in the HF literature that aspects related to resources can constitute barriers for the integration of ergonomic knowledge in design. Prior studies have mainly focused on issues related to ergonomists' lack of accountability in relation to the cost benefit of integrating ergonomics in design, and to 'time and costs' as conflicting criteria for implementing ergonomic input (Haslegrave and Holmes, 1994; Theberge and Neumann, 2013; Whysall et al., 2006; Wulff et al., 1999a, 1999b). These issues were also identified in the present study; however, I find that previous studies have paid only minor attention to the shaping of resource issues as constraints for ergonomists involved in design projects. A possible reason for this is that these studies focus mainly on manufacturing companies or design organizations, where resources for the ergonomic support function are already allocated – either in the form of an internal support function or from an external position, by researchers or external advisors. In the present study, no prior resources were allocated for the ergonomists acting in a support function to the engineering designers in the design process.

The fact that responsibility is split between clients and consultants conflicts with the benefit of involving ergonomists in design. Such involvement should be evaluated on the basis of a joint 'consultancy and client' perspective, as the benefits can largely be linked to increased system performance in the client organization (Goggings at al., 2008; Neumann and Dul, 2010; Oxenburgh et al., 2004). A great challenge in the engineering consultancy setting is that engineering designers are separated, both organizationally *and* financially, from the potential savings of involving ergonomics in design. In engineering consultancies, integrating ergonomics in design only constitutes a financial benefit to the extent that the clients are willing to pay the extra expenses of involving ergonomic services in design projects – or if the engineering consultancy can achieve a competitive advantage by delivering high quality solutions based on combined services.

2) Epistemic differences, domain-specific interests and uneven balance of power limit integration

The integration of ergonomic knowledge in design projects was also limited by intergroup barriers between engineering designers and ergonomists. Epistemic differences involved elements of prejudice toward each other's practices, a "them and us" perspective,

different design perspectives and criteria, a lack of common language, and different understandings of the value of integrating ergonomics in design. These findings correspond to the findings of other important contributions in the literature (Burns and Vicente, 2000; Neumann et al., 2009; Waterson and Kolose, 2010; Wulff et al., 1999a, 1999b). Thus, the intergroup barriers between ergonomists and engineering designers seem to be a premise for the integration of ergonomic knowledge across various design settings; this involves consequences, such as conflicting criteria. The intergroup barriers can be explained by the fact that ergonomists and engineering designers belong to fairly different object worlds or communities of practices (Broberg and Hermund, 2007; Bucciarelli, 1994; Wenger, 2000; Wulff et al., 1999a).

Barriers related to domain-specific interests and an uneven power base between ergonomists and engineering designers were also identified. The engineering designers were in charge of the design processes and their regular practice, a practice that the ergonomists in many ways strived to become an integrated part of. Only a few studies in the HF literature have contributed to understanding what elements of power and political processes mean for the possibilities for integrating ergonomic knowledge into design (Broberg and Hermund, 2004; Gerrety and Badham, 1999). These studies suggest that the challenges of promoting an ergonomic agenda in design can be linked to the actors' different professional perspectives and interests. In accordance with my findings from the present study, Gerrety and Badham (1999) find that other actors in sociotechnical change processes may also possess the power to carry out their activities, plans and goals in ways that circumvent the plans and goals of ergonomic actors.

Drawing on Carlile (2002, 2004), I find that problematic issues related to working across different knowledge domains can be explained by the 'path-dependent nature of knowledge' and by knowledge not only being *located* within practice but also *invested* in practice, in terms of the time and resources spent to acquire and maintain a certain knowledge base. Similar to Gerrety and Badham (1999), Carlile (2004) also argues that problematic situations can occur when a powerful actor group reuses a common knowledge path that limits the ability of other actor groups to represent their domain-specific knowledge.

3) Objects used as means of transferring ergonomic knowledge over a distance face difficulties in creating a distant effect

Across the data material, I found that objects (e.g. reports, data bases, recommendation lists) were used as a mean of transferring ergonomic knowledge over a distance to other design actors. This was identified both at project level and at corporate level. However, several shortcomings in using this approach were also identified.

First of all, objects used as a means of transferring ergonomic guidelines in design only specified certain aspects of the workplace to be designed, while other relevant aspects were left out. In meetings with downstream actors, objects also hold an 'interpretative flexibility', which means that while guidelines in some cases were transferred to the design solutions, there were also times when guidelines were misinterpreted by downstream actors; or they were disregarded, if the ergonomic guidelines conflicted with other design criteria. Relying on objects to pass on ergonomic knowledge in design carries the risk that ergonomic input may be disregarded, if the input in some way clashes with other design actors' perspective on the workplace to be designed. This was also found by Wulff et al. (1999a, 1999b). I also identified barriers related to 'information overload' or problems with accessibility or awareness of the ergonomic tool among engineering designers, as previously identified by Buns and Vicente (1996) and Wulff et al. (1999a, 1999b, 2000). Broberg (2007) also found that in general handbooks and computerized ergonomic information were rated of low value to engineering designers. Hence, when objects are used as the only means of transferring ergonomic knowledge in design, they face problems creating distant design effects.

Drawing on Carlile (2002, 2004), the choice of using an "information transfer" strategy underestimates the complexity of the boundary between ergonomists and engineering designers, since the cost of entering ergonomic documents *and* complying with the ergonomic guidelines and requirements is too wide-ranging for the engineering designers.

4) A traditional ergonomic approach can limit integration in a business-driven design setting

According to the HF literature and IEA's definition of ergonomics, the profession revolves around a joint focus on human well-being *and* overall system performance. In the present case study, however, I found that when the ergonomists entered a design project, their primary focus was on the human well-being part of ergonomics with an aim of creating good working conditions for end users. One ergonomist, who had been engaged in the hospital case for a couple of years, said that he had learned a lot from being engaged in design and had adopted a broader focus on optimal design solutions. He further explained that when entering design, the traditional ergonomic approach was to focus solely on human well-being. He continued:

> Ergonomists have a tendency to set the bar high… It has to be the best of the best, and it can't be any other way. But it can. You just have to find the areas where it is okay and where it is not. (Interview - ergonomist)

In a resent Canadian study by Theberge and Neumann (2013), the findings are similar. Based on interviews with 21 ergonomists, these authors found that the ergonomists primarily focused on safety concerns, and that the predominant perception of the field also was safety oriented. They argue that while safety may be the basis for the growing presence of ergonomists in workplace settings, this focus also limits application of ergonomics.

The dominating focus on workers' well-being also seems to be predominant in the Danish Labor Inspection (DLI), which was sometimes called upon in the hospital case to inspect design solutions. An ergonomist, from the hospital case reported that DLI had difficulties in seeing the broader perspective of innovative ideas on future work processes. Their evaluation of design solutions was based on current work processes at existing hospitals and solely from the perspective of the future workers at the hospital. Hence, the Labor Inspection's predominate focus on the workers' well-being might constitute a barrier to introducing more innovative and nuanced perspectives on design solutions.

When engaged in design, ergonomists were sometimes met with: "But you should spend your time changing the OHS legislation, instead of spending it on telling us all that" (Interview - ergonomist). According to Bucciarelli (1994), imposing regulative constraints in an engineering design practice will often be met by resistance, because regulations are looked upon as "not invented here". These findings suggest that the strong ties the ergonomic discipline has to authorities and legislation contribute to creating a barrier for the discipline, because this contributes to maintaining a narrow focus, *and* because the regulative constraints are met by engineering designers with suspicion. Similar has previously been pointed out in other valuable contributions (Ahasan and Imbeau, 2003; Dul et al., 2012; Dul and Neumann, 2009; Pikaar, 2007; Theberge and Neumann 2013). More specifically, Dul and Neumann (2009) find that managers often perceive of ergonomics as "occupational health and safety and related legislation" (Dul an Neumann, 2009, p. 745). They argue that this perception isolates the ergonomic profession from being included in more strategic business goals and planning activities.

5) Lacking organizational initiatives and organizational structure to support integration

Several actors in the company reported that the division-based structure did not promote the integration of ergonomic knowledge in design; rather, the focus was on optimizing profit in each individual division. The focal points of the company's performance measurement system reinforced these structural barriers, as the main goal of the managers in the divisions was to generate profit within their own division, while selling the services of other divisions was rated much lower. As described in chapter 2 structural setups can constitute barriers for integrating

ergonomic knowledge in design processes (e.g. Neumann et al., 2009; Perrow, 1983). In learning and knowledge management literature it is argued that structural arrangements can be used strategically to guide knowledge and learning processes, as well as constitute a barrier for these processes (e.g. Newell et al., 2002; Senge, 1990). In the present study, I found that the ergonomists and engineering designers were physically and organizationally separated from one another, both in the matrix organization and in the division-based organization. Studies and theoretical viewpoints stress, however, the importance of face-to-face interaction between actors to facilitate work processes and knowledge sharing (e.g. Bucciarelli, 2004; Newel et al., 2002; Perrow, 1983; Wenger, 2002; Wulff et al., 1999a, 1999b). We can only speculate about how the integration processes would have developed, if the ergonomists, for instance, had been placed organizationally in the various engineering design departments, however I hypothesize that the physical separation of ergonomists and engineering designers also constituted a barrier for integration.

During the first five years after the acquisitions, different organizational initiatives were introduces to promote the integration of ergonomic knowledge into design processes. However, I found that these initiatives were mainly directed toward institutionalizing routines or creating a change in the mindset of the organization. There was a lack of supporting initiatives such as brokering and feedback loops, which could have stimulated the emergence of a new practice at and across different levels of the organization.

7.2 Integrating ergonomic knowledge at project level

In the initiatives to integrate ergonomic knowledge into design project the engineering designers had a central role both as design actors and as project managers. The second sub-question relates to this premise, as it focuses on how ergonomics knowledge can be integrated into the engineering design processes in a way which is valued by the engineering designers to some extent. The second sub-question relates to this:

How can ergonomic knowledge effectively be integrated in engineering design projects, in a way which is appreciated by engineering designers?

Figure 10 presents a combination of aggregated possibilities and factors that can help stimulate the integration of ergonomic knowledge into the engineering design project's design. The following sections elaborate and discuss these possibilities.

1) **The use of boundary objects can help to facilitate dialogues between ergonomists and engineering designers**
2) **Objects used as means of transferring ergonomic knowledge over a distance should be supported by face-to-face interactions**
3) **Ergonomists should learn the engineering design terminology and be prepared to compromise on ergonomic inputs to gain impact on design**
4) **Design projects should be organized to support interactions and dialogues between design actors throughout the design processes**

Figure 10: Main possibilities and promoters at project level

1) The use of boundary objects can help to facilitate dialogues between ergonomists and engineering designers

Boundary objects (e.g. layout sketches) can help mediate a dialogue between engineering designers and ergonomists. Based on the case of the sterile processing plant, my findings show that especially when the object became malleable, it was able to facilitate a dialogue in which pros and cons of different design solutions could be discussed across knowledge domains. With the layout sketches placed between them, the design actors could present arguments and learn about the differences and dependencies between them *and* the consequences of different design solutions (Carlile, 2002).

This finding resonates with the findings of Broberg et al. (2011) and Boujut and Hisarciklilar (2012). Based on a study in the area of participatory ergonomics, Broberg et al. (2011) suggest that boundary objects that have the characteristics of being 'object-in-the-

making', being 'malleable and flexible', and having 'build-in affordances' are particularly effective in facilitating dialogues between different design actors, because they allow the actors to design *with* the object.

I also identified limitations to using boundary objects to bring ergonomic knowledge into design. Objects such as layout sketches, which have physical similarity to the object being designed, invite inputs related to the setup of the new workplace, whereas other important aspects of ergonomics, such as the psychosocial or organizational aspects, may slip out of focus. Hence, when using objects as means of supporting dialogues between design actors, it is important to consider how the more organizational or psychosocial aspects of ergonomics can be brought into the dialogue as well. This is an area in which additional research is needed. Boujut and Hisarciklilar (2012) point out another limitation to the use of boundary objects. They find that in particular objects with physical similarity to the object being designed, there tends to lack a memory feature in relation to the oral discussion; therefore, to capture important aspects of the design dialogue, boundary objects should be equipped to enable the possibility of adding explanatory annotations. Alternatively, boundary objects should be supported by other types of objects such as written reports, where the underlying reasoning behind different design choices can be explained.

2) Objects used as means of transferring ergonomic knowledge over a distance should be supported by face-to-face interactions

Section 7.1 discusses the shortcomings of using objects as a means of transferring ergonomic knowledge over a distance, but the findings also illustrate possible benefits of using this approach. In the hospital case, the ergonomists received recognition for their contributions to the overall design manual of the project. The CEO of the hospital project commented that the ergonomic inputs to the design manual (such as standards for door width) had contributed to a more uniform design of the different parts of the hospital and improved the design's quality. In the case of the sterile processing plant, several of the guidelines were also embedded in the design of the plant. Consistent with Wulff et al. (1999a, 1999b), my findings show that one of the shortcomings of using written documents as a means of transferring ergonomic knowledge to engineering designers was especially related to the incidents when ergonomic input in some way conflicted which other design criteria.

To overcome this shortcoming, Wulff et al. (1999a, 1999b) suggest that ergonomic input should be formulated as specific requirements, while general recommendations should be avoided. Rogers and Armstrong (1977) present similar arguments. In the case of the sterile processing plant, I analyzed the correlation between specific/general formulations of ergonomic inputs and the inputs implemented in the design, but I did not find evidence supporting the

suggestion by Wulff et al. (1999a, 1999b). After examining the findings across the case material, I am able to elaborate this. The central aspect is not whether the ergonomic input is specifically or generally formulated; rather, it matters whether or not the input is *translated* to the specific context of use and the degree to which the organizational arrangement of the design project allows for follow-up dialogues between engineering designers and ergonomists, which also is suggested by Wulff et al. (1999a, 1999b). Finally, it should also be noted that this PhD study supports Broberg (1999), who argues that ergonomic information tools should be incorporated in the tools or database with which the engineering designer is already acquainted, in order to increase accessibility.

3) Ergonomists should learn the engineering design terminology and be prepared to compromise on ergonomic inputs to gain impact on design

The possibilities to integrate ergonomic knowledge in design are also linked to the competencies of the ergonomists. This study suggests that familiarity with the engineering design terminology enhances the ergonomists ability to act in design. The study also shows that being prepared to compromise on ergonomic inputs is important in relation to gaining an actual impact on design. One of the ergonomists from the hospital case stated:

> You have to engage in dialogue and speak their [engineering designers] language. Then it is possible to get your messages and counseling through. But you have to compromise, there is no other way. This has been the greatest realization for me – you can't be that kind of ergonomist who states: 'It can only be my way'. (Interview - ergonomist)

By engaging in design, this ergonomist learned that design is a process with many facets, where negotiation and tradeoffs are a part of the process of reaching a joint solution. This finding is supported by several other authors (Béguin, 2011; Bucciarelli, 1994; Burns and Vicente, 2000; Haslegrave and Holmes, 1994; Wulff et al., 1999a, 1999b). These studies also stress the importance of being able to speak the engineering design language in order to be able to provide effective ergonomic counseling. In Waterson and Kolose's (2010) study in an engineering company in the defence industry, they found a number of cases where ergonomists tried to promote the integration of ergonomics in design by "actively trying to adopt the perspective or tap into the ''mindset' of engineering groups within the company" (Waterson and Kolose, 2010, p. 489).

Drawing on the discussion in section 7.1 about the regulative ties of the ergonomic professions, I also argue that ergonomists should tone down the regulatory demands as much as possible in the dialogue with engineering designers. An alternative strategy is to attempt to link

the ergonomic initiatives to the engineering designers' goals rhetorically by using 'goal hooking' (Poggi, 2005). The underlying idea here is that it may be easier to implement ergonomic initiatives, if the engineering designers can see that they contribute to fulfilling their own goals (Dul and Neumann, 2009; Dul et al., 2012; Theberge and Neumann, 2010; Whysall et al., 2006).

4) Design projects should be organized to support interactions and dialogues between design actors throughout the design processes

Proximity and face-to-face interactions between engineering designers and ergonomists appear to facilitate the integration of ergonomics in design. In the hospital case, where ergonomists were involved throughout the design process, I found that both ergonomists and engineering designers were in favor of this approach. The benefits were ascribed to, among other things, avoiding the 'audit effect' where ergonomists are only occasionally called in to comment on design suggestions without fully understanding the design conditions or the design process. This was seen when the DLI came to inspect design solutions (see section 7.1). This viewpoint is also found in Wulff et al. (1999a), who argue that "close personal contact appears important for positive result" (Wulff, 1999a, p. 205). The audit approach also carries the risk of causing costly redesigns (Béguin, 2011). The rewarding effects of face-to-face interactions between design actors from different knowledge domains is also emphasized by authors in other research areas (e.g.Boujut and Hisarciklilar, 2012; Bucciarelli, 1994; Carlile, 2002, 2004; Newell et al. 2002; Wenger, 2000).

In the case of the sterile processing plant, an ergonomist was only invited to take part in a limited part of the design process, namely during planning and design (see Figure 6). It turned out however that many decisions affecting working conditions were made during the following phases, all the way through to the operation phase, and issues that the ergonomist and the design team had not been able to foresee also emerged. Hence, continuous dialogue with an ergonomist about design solutions is recommendable, for instance, through follow-up meetings. Pikaar (2007) supports this and recommends that ergonomists be involved during implementation and commissioning phases as well.

While a recommendation to involve ergonomists in face-to-face interactions throughout the design phases is strongly related to an *effective* integration of ergonomic knowledge in design, it will most likely clash with what is actually appreciated by engineering designers. The downsides of involving ergonomists in design were referred to by several engineering designers as an increase in complexity in design projects *and* as being costly. An alternative is recommended by Pikaar (2007), who suggests that ergonomists should strive to become project managers in design projects, since this role offers an opportunity to be involved throughout the design process.

7.3 The organizational setup in the engineering consultancy

Overall, I found that the development of a new practice around integrating ergonomic knowledge in design remained discrete. The seeds of a new practice were identified in 'pockets', mainly at the individual level, project level, or in domain-specific contexts. No overall combined practice was identified. In this section, I address how ALECTIA can support the development of a combined practice by reconsidering the organizational structure in the company and introducing different organizational initiatives, as I answer the third sub-question:

What does the integration require organizationally of the engineering consultancy?

In Figure 11, I present the main suggestions for how ALECTIA can support the development of a combined practice. These suggestions are related specifically to the organizational setup in ALECTIA, but engineering consultancies that wish to integrate ergonomic knowledge in design are expected to benefit and learn from the suggestions as well. The contributions and the discussions below are based on the assumption that ALECTIA can benefit strategically from integrating ergonomics in the engineering design projects. In this chapter, I draw mainly on the theoretical framework presented in chapter 4, as no prior studies in the HF literature focus specifically on the organizational implications of integrating ergonomics in design processes in the engineering consultancy setting.

1) **Develop shared strategic goals across divisions/business areas to guide integration processes**
2) **Consider altering the organizational structure and/or adjust the focal points in the performance measurement system**
3) **Introduce a combination of various organizational initiatives, and be prepared to alter initiatives, if shortcomings become apparent**
4) **Focus on selling the combined services and promoting a holistic view on resource across design and operation phases**

Figure 11: Main possibilities and promoters in the engineering consultancy setting

1) Develop shared strategic goals across divisions/business areas to guide integration processes

A shift in the strategic focus in ALECTIA was identified during the time frame of the PhD study. While the proclaimed strategy of the company remained the same, the introduction of the division-based structure also implied that the overall differentiation strategy was replaced by strategies formed locally in each division. Several different theoretical contributions to the

literature argue that a company's competitive advantage lies in a company's ability to dynamically combine and coordinate knowledge processes across the different knowledge assets in the company (e.g. Barney, 1995; Brown and Duguid, 2001; Wenger, 2000). According to Newell et al. (2002), "agenda formulation" is a central element when aiming to innovate existing work processes. Hence, if ALECTIA wishes to exploit fully the potential of having in-house ergonomic competencies, the company should aim at developing a shared agenda around integrating the ergonomic competencies in engineering design processes.

The importance of putting ergonomics on the strategic agenda and having managerial support has been highlighted by many contributions to the HF literature (e.g. Dul and Neumann, 2009; Neumann et al., 2009; Perrow, 1983). However, creating a shared agenda requires more than a proclaimed strategy to guide integration processes. It also requires initiatives and structures that can facilitate and coordinate the integration and innovation processes. This is addressed in the following sections.

2) Consider altering the organizational structure and/or adjust the focal points in the performance measurement system

Several actors found that the division-based structure hindered the integration processes, due to the dominant focus on maximizing the profit performance of the individual divisions. These structural barriers were influenced by the focal points of the company's performance measurement system. The division managers' main goal was to generate profit within their own division, while goals related to selling combined services were rated much lower. At project level, the main goal of maximizing the profit of each individual project also hindered integration.

Perrow (1983) also reports on structural barriers and points to the reward structure as being crucial for the possibilities to integrate ergonomics in design. Contributions to the learning and knowledge management literature also find that structural arrangements can constitute a barrier for knowledge and learning processes and also be used as a way of guiding them (e.g. Newell et al., 2002; Senge, 1990). Likewise, Brown and Duguid (2001) point to motivating elements as important factors in relation to promoting cross-disciplinary work processes. In line with these contributions, ALECTIA can motivate and guide the development of a combined practice by including 'selling cross-disciplinary services' as a main goal in performance measurement systems, both at the level of the managers, the middle-manager level, and the consultant level.

The seeds of a new practice emerged primarily through face-to-face interactions between engineering designers and ergonomists, and proximity between engineering designers and ergonomist was also identified as a promoting factor. In order to stimulate the development of a new practice, top management in ALECTIA should consider how the organizational

structure of the company could be altered to facilitate the interactions between engineering designers and ergonomists. One suggestion is to physically place the ergonomists in the engineering design departments. Similarly, Perrow (1983) argues that ergonomists should be placed "physically near designers so they can interact informally and build individual and group bonds" (Perrow, 1983, p. 526). Reintroducing a matrix-based organization or a team-based structure is also a possibility.

3) Introduce a combination of various organizational initiatives, and be prepared to alter initiatives, if shortcomings become apparent

Corporate initiatives to institutionalize routines, such as the delivery model and the staffing procedure (see Table 6), were never fully implemented in practice, possibly due to a lack of supporting initiatives that could stimulate the emergence of a new practice at and across different levels of the organization (Garud and Kumaraswamy, 2005). Based on several theoretical contributions, I argue that the development of a new practice requires the introduction of a combination of various organizational initiatives (Carlile, 2002, 2004; Garud and Kumaraswamy, 2005; Newell et al., 2002; Wenger, 2000). Garud and Kumaraswamy (2005) argue that the diverse nature of knowledge processes requires that knowledge management be "distributed among a team of individuals with diverse epistemic leanings" (Garud and Kumaraswamy, 2005, p. 27). Furthermore, they recommend that the consequences of introduced initiatives constantly be monitored, and decoupled if unforeseen and undesired consequences of an initiative emerge. In the following, I address some initiatives that can stimulate the development of a combined practice.

The use of knowledge repositories – At corporate level, the use of objects such as knowledge repositories should be considered carefully. The already introduced delivery model did not seem to be able to promote the integration of ergonomic knowledge into design. First of all, it seemed that the tool was not used much, and secondly, the domain-specific contributions were not *translated* so they could be understood by other knowledge domains. Moreover, the tool model also contained many layers, and countless ergonomic documents were included. To enhance the usability of the tool, the domain-specific contributions should be redeveloped based on dialogue between ergonomists and engineering designers. The tool should however also be supported by additional organizational initiatives that can stimulate the social and behavioral processes. These are rather important, especially in the early stages of developing new work processes (Newell et al., 2002).

Cross-disciplinary forums – In current design practice in ALECTIA, there are no institutionalized feedback loops to ensure that experiences in integrating ergonomic knowledge into design are spread from the project level to the collective level. In the ergonomic division, a forum for 'work space design' exists and contributes to knowledge sharing among the ergonomists. However, forums where engineering designers and ergonomist can jointly discuss their experiences in integrating ergonomic knowledge in design and discuss how a joint practice might be established and stimulated are lacking. Cross-disciplinary forums could be established in connection with a mandatory project evaluation. Cross-disciplinary forums could also be established in each of the different business areas within which ALECTIA operates.

Brokering initiatives – Strategic 'brokering' was used to link the marketing managers (see Table 6), but apart from this initiative, brokering was not used as a strategic tool to build bridges between engineering designers and ergonomists. Both Wenger (2000) and Newell et al. (2002) point to brokering initiatives as being especially important in the development of new practices across different knowledge domains. This suggestion resonates with the findings of this study, which showed that the seed of a new practice emerged especially in the meeting between ergonomists and engineering designers. Without using the term brokering, Perrow (1983) also recommends top management to promote the integration of ergonomic knowledge in design by strategically linking ergonomists and engineering designers in various ways. In a business-driven design context with a strong focus on employees invoicing degrees (percentage of working hours which can be invoiced to clients), the value of brokering initiatives can easily be overlooked since they "may not contribute directly to any specific outcome" (Wenger, 2000, p. 236). However, I strongly recommend ALECTIA to encourage brokering and actively place ergonomists in the engineering departments (or the other way around) as previously suggested.

Institutionalize routines – At the time of writing this thesis, a standardization process with the aim to develop "standardized ergonomic design services" has been initiated in the engineering consultancy. This can be a very important step towards reduce the cost of integrating ergonomics into design. However, at the moment this process is an isolated initiative in the ergonomic division, hence it is strongly recommended to continue this process. However in order to promote a *combined* practice, it is important that both ergonomists and engineering designers participate in a process of discussing and negotiating different elements of more institutionalized routines.

4) Focus on selling the combined services and promoting a holistic view on resource across design and operation phases

A prerequisite for being able to benefit strategically from integrating ergonomic knowledge into design in a business driven design setting is that clients are willing to pay for the combined services. Therefore, to promote the development of a new practice and fully exploit the potentials of having ergonomic competencies in house, special attention should be paid to *selling* the ergonomic services as part of the engineering design projects and pursuing the ergonomic ambitions of clients. However, this is probably not an easy task. In the case studied, most of the engineering designers who are in charge of both the sales processes and the design processes have no tradition for selling ergonomics as a part of the design tasks. Likewise, most ergonomists have no tradition for selling engineering services to their regular clients.

Organizationally, the development of a combined practice could be guided by including 'selling cross-disciplinary services' as main focal point in the performance measurement system. Another possibility is to provide ergonomic training to engineering designers to enable them to address ergonomics during sales, and similarly provide engineering design training to ergonomists to promote their ability to sell engineering services to their clients, and possibly also strengthen their possibilities to act in design projects. This strategy can be supported by developing an ergonomic idea catalogue for the engineering designers to include in sales. In order to be useful to the engineering designers, such an idea catalogue should be developed based on dialogues between ergonomists and engineering designers. Another potential strategy is to team up the engineering designers and ergonomists in sales processes. This strategy was used successfully in one of the case studies. Selling ergonomic services as a part of engineering design projects also calls for adopting a holistic view of resources across design and operation phases – and addressing the potential benefits of including ergonomic services in the design processes in dialogues with clients.

8 Conclusion

The present study contributes new perspectives on possibilities and barriers for integrating ergonomic knowledge into engineering design processes by focusing specifically on integrating activities in an engineering consultancy setting.

The design setting in engineering consultancies can be characterized as business driven. In this setting, resources are shaped as constraints for the possibilities for integrating ergonomic knowledge into the engineering design processes. The resource constraint is shaped by such factors as constant focus on maximizing project revenue and lack of accountability for the cost-benefits of integrating ergonomics in design. The constant focus on optimizing design project revenue clashes with the rationale behind integrating ergonomics in design, which should be evaluated on the basis of a full life cycle perspective on designed work systems across both design and operational phases. In this business driven setting, possibilities for integrating ergonomic knowledge in design is strongly linked to clients' willingness to pay for ergonomic services being included in engineering design tasks.

Similar to earlier contributions in the HF literature, this study finds that different social and organizational factors have an impact on possibilities to integrate ergonomic knowledge into engineering design projects. More specifically, I find that the proximity and face-to-face interactions, which arises from the ergonomists and engineering designers being employed in the same company, constitutes a supporting factor for the possibilities to integrate ergonomics in design. Elements such as organizational structure, physical arrangements, and the focal points of the performance measurement system in the company were found to be strong barriers for the integration.

The competencies of the individual ergonomists also have an impact on possibilities to integrate ergonomic knowledge in design. The ergonomists' ability to navigate, act strategically, and compromise on ergonomic inputs is important in relation to getting ergonomic counseling through to the engineering designers. Familiarity with the engineering design terminology and the setup of design projects seems to enhance the ergonomists' ability to act in design.

The study also brings focus to the often unrecognized role objects have when integrating ergonomic knowledge in design. Objects play a central role in bringing ergonomic knowledge into action in the design projects, both in direct communication between design actors and in attempts to transfer ergonomic knowledge to other design actors over a distance. In the direct communication between ergonomists and engineering designers, objects help to facilitate a dialogue across knowledge domains. When objects are used as a means of transferring ergonomic knowledge over distances, difficulties emerge due to the social nature of design work. However, when such objects are supported by ergonomists who participate actively throughout the design phases, they can help to promote integration activities.

8.1 Further research

During the course of the PhD project, different ideas for further research emerged, based both on insights gained through the study and the methodological choices made along the research journey. Here I shortly touch on a few of them.

The present study is based on a single embedded case study in an engineering consultancy. It would be highly relevant to expand the findings of this study by comparing and contrasting them to possible integration activities in other engineering consultancies, which like ALECTIA have substantial ergonomic department(s) in house.

Another possible direction to take in future research projects is to conduct projects oriented more toward action research, where the researcher could help engineering consultancies address some of the barriers identified in this project. One possibility would be to help engineering consultancies stage meetings between engineering designers and ergonomists, where they could jointly address their experiences in integrating ergonomic knowledge in design with the aim of developing a combined practice across the knowledge domains.

Finally, it would also be highly relevant to go further into exploring the prospects of using objects as a means of integrating ergonomic knowledge in design. It would be particularly interesting to conduct a study with focus on exploring how objects can also be used as a means of bringing the more organizational and psychosocial aspects of ergonomics into the dialogue between design actors.

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Appended articles

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Integrating ergonomics knowledge into business-driven design projects: The shaping of resource constraints
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Integrating ergonomics in design processes: a case study within an engineering consultancy firm

Lene Bjerg Sørensen[a,b*] and Ole Broberg[a]
[a] *Department of Management Engineering, Technical University of Denmark Building 424, DK – 2800 Lyngby, Denmark*
[b] *ALECTIA, Teknikerbyen 34, DK – 2830 Virum, Denmark*

Abstract. This paper reports on a case study within an engineering consultancy firm, where engineering designers and ergonomists were working together on the design of a new hospital sterile processing plant. The objective of the paper is to gain a better understanding of the premises for integrating ergonomics into engineering design processes and how different factors either promote or limit the integration. Based on a grounded theory approach a model illustrating these factors is developed and different hypotheses about how these factors either promote and/or limit the integration of ergonomics into design processes is presented along with the model.

Keywords: engineering design processes, organizational design, explorative case study

1. Introduction

Integration of ergonomics into design processes can contribute to the creation of safe and healthy work places [1-3,5-7]. In Denmark there has over the past five years been a development in the area of engineering consulting, where a lot of the larger engineering consultancy firms have established ergonomic divisions within the company organization. This has happened while the public founding for occupational health services has been phased out and the area has been privatized. From an ergonomic point of view this is an interesting development as it might create new possibilities to integrate ergonomic knowledge in the design of new work places. However the integration of ergonomic knowledge in engineering design processes is new to a lot of the ergonomists and the engineering designers.

In this paper a case study within one of these engineering consultancy firms is presented, where engineering designers and an ergonomist were working together on the design of a new hospital sterile processing plant. The objective of this paper is to get an insight into how ergonomic knowledge can be integrated into engineering design processes and get a deeper insight into how different aspects influence the integration of ergonomic knowledge in design processes. The research question for the paper is:

What promotes the integrating of ergonomic knowledge in design processes and what are the limitations?

2. Method

An explorative case study was conducted. The case material was collected through interviews, a document study and to a minor degree observation. 12 semi-structured interviews were carried out within the engineering consultancy firm and the hospital organization. The first author also visited the sterile processing plant, observed the employees while they were working and interviewed them concurrently. The engineering consultancy firm provided full

*Corresponding authors: lbjso@man.dtu.dk e-mail lbso@alectia.com

access to the company's database for document and project handling. Here a total of 9251 documents were related to the project.

Based on a grounded theory approach [4] the case study was unfolded: The documents were sorted and prioritized where the focus was to uncover all documents revealing anything about the meeting between design and ergonomics. The document study involved going through minutes of meetings, project presentations, project plans, drawings, working documents and an ergonomic guideline document. To get an insight on the timeline of the project and to uncover when and how ergonomics was integrated into the project a physical wall with a timeline displaying all the relevant paragraphs of the explored documents was created. This visual method was very useful to create an overview of the design process. Furthermore all interviews were transcribed. Afterwards all data material was coded for the theme "ergonomic knowledge in design processes". In this process codes were formed and though rearranging the different codes, categories emerged. The model presented in Figure 1 was constructed when searching for relations between the categories. In this process hypotheses about the correlations was formed and the model can in itself be seen as a hypothesis.

3. Case description

When the case study unfolded the ergonomists had been employed in the engineering consultancy firm for a couple of years. Organizationally, spatially and financially the engineering departments and the ergonomic departments were separated.

The case study concerned the design of a new sterile processing plant and the engineering consultancy firm was to do the logistics and the layout of the sterile processing plant. For the engineering designers this is a standard configuration job, where they adapt a standard design for sterile processing plants to the local settings at the hospital in question. However in this specific case the locations designated for the sterile processing plant was rather cramped and based on preliminary discussions with the head of the ergonomists "hospital group" the engineering designers decided to involve one of the engineering consultancy firm's own ergonomists in the design job. The ergonomist chosen for the design job had no prior experience in being part of a design team. It was also the first time for the project manager to involve an ergonomist in one of his projects.

Besides the ergonomist, the design team consisted of a consultant, C1, who was a nurse, the project manager, who was a trained engineer, several other engineers. The head of the hospital division in the engineering consultancy firm also participated in the design. Prior to engaging the ergonomist in the design job the design team had carried out user-meetings, conducted a capacity analysis and made an outline for the logistics and flow in the sterile processing plant. Sketches for the layout of the plant had also been made. The job of the ergonomist was to complete an ergonomic guideline document stating her recommendations for the sterile processing plant. In the design process she cooperated mainly with C1 and was invited to visit the future locations for the sterile processing plant along with C1 where they spoke to some of the future users of the sterile processing plant. Furthermore the project manager, C1 and the ergonomist had meeting where the project manager and C1 presented the ergonomist with their layout sketches. The ergonomist commented on the sketches and in this way contributed with her knowledge on ergonomics. The ergonomist also participated in a couple of the internal project meeting in the engineering consultancy firm. After the completion of the ergonomic guideline document the ergonomist left the project. For the rest of the design team the design job ended shortly hereafter with the handover of a project proposal summing up their design solutions. The ergonomic guideline document was circulated along with the project proposal to actors inside the hospital organization and to the hospital's turnkey contractor.

The hospital was in charge of the implementation and start-up phases at the sterile processing plant. In this phase they once again chose to contact the engineering consultancy firm for assistance. A consultant, C2, who was also a trained nurse, was assigned the job. Her job was to support the hospital with overall guidance, help the hospital do specification requirements of new equipment and implemented a computers system for stock-control. She was also handed the ergonomic guideline document.

When the first author visited the sterile processing plant it turned out that not all recommendations given in the ergonomic guideline document had been implemented at the work place. It also became evident that there were issues related to ergonomics that the ergonomist and the project team had not addressed, for instance problems related to the psychosocial working environment and chemical aspects.

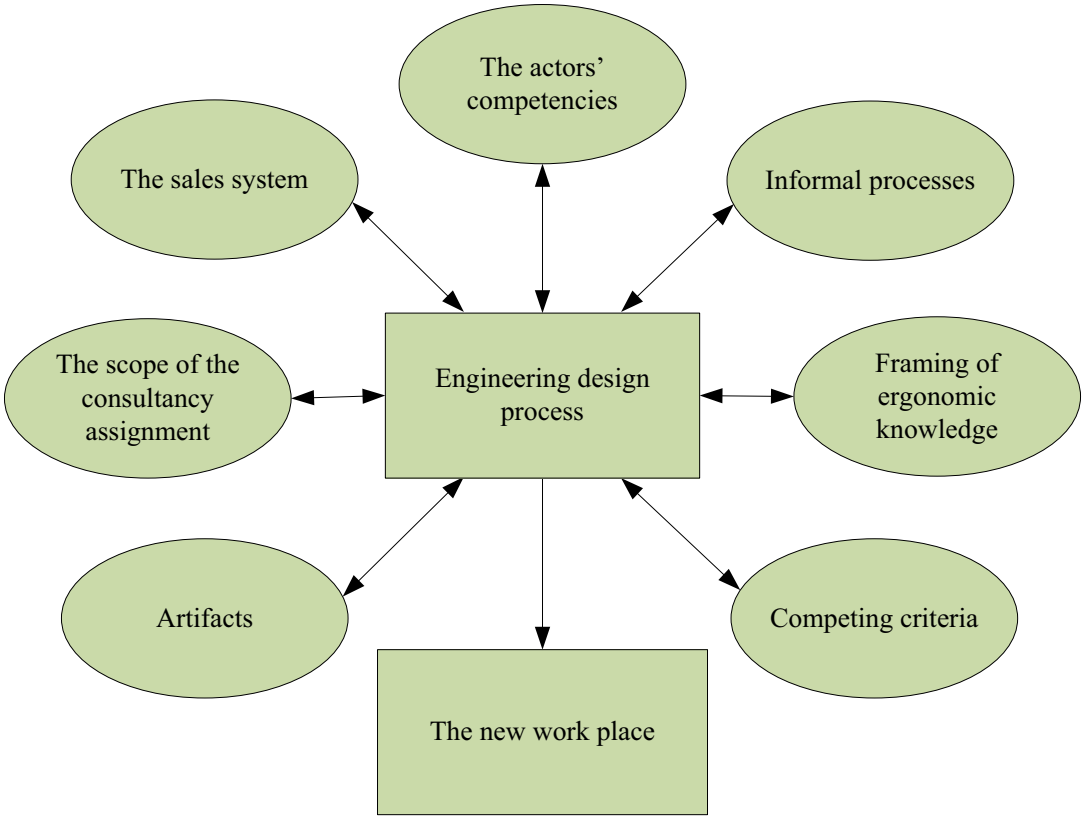

Figure 1
The different factors affecting the integration of ergonomics into work place design

4. Results

Based on the case study described above the model presented in Figure 1 was formed. The model illustrates the different factors which emerged through the data analysis.

In the middle of Figure 1 is the **engineering design process.** This box was placed in the middle of the figure to illustrate that the engineering design process is a premise of integrating ergonomic knowledge into design of new work places inside an engineering consultancy firm. Hypotheses about how the categories surrounding the "engineering design process" promote and/or limit the integration of ergonomics into the engineering design process were formed and these are described in the following.

4.1. The actors' competencies

The actors' competencies have great impact on the engineering design practice when it comes to integrating ergonomics in the engineering design process. For all the involved actors it is rather new to integrate ergonomics in design processes and this leaves them with a question of how and when to integrate ergonomics in the design process.

Engineering designers have experience in being part of engineering design process, but the area of ergonomics is new to them and this limits their ability to see how and when it is beneficial to integrate ergonomics into the engineering design practice. It promotes the integration of ergonomic knowledge when the engineering designers identify challenges they consider to be related to ergonomics, such as a lack of space.

The ergonomists on the other hand have professional competencies in the area of ergonomics and

have a lot of experience and knowledge on the ergonomic-related problems that might arise at a given work practice. The engineering designers see this knowledge as beneficial because the engineering designers normally don't see the day to day running of the work practices they design. This promotes the integration of ergonomic knowledge into the engineering design practice. However only a few ergonomists have experience with being part of a design process and this limits the integration of ergonomic knowledge in the engineering design practice. The terminology used in engineering design is unfamiliar to the ergonomists, and this might limit their ability to bring ergonomic knowledge into action when engineering designers discuss aspects related to the design process or the design solutions.

The case study shows that consultants, trained as nurses, participate in design processes in close cooperation with the engineering designers. They contribute with a practical founded knowledge on both work practice and ergonomics and are deeply involved in the user involvement. The ergonomic professionals describe themselves as having a holistic view on the work practice, having a lot of experience with user involvement and having good competencies in fulfilling the role as a process consultant. Even so they are only invited to participate in the design process as a support function. This limits the integration of the ergonomic expert knowledge. It seems that the ergonomists do not have the competencies to "sell" their process-related competencies to the engineering designers, and this limits the possibilities for bringing their ergonomic knowledge into action. However when both the consultants and ergonomists are involved in projects the combination of the consultant's practical experience and the ergonomist's expert knowledge on ergonomics is a fruitful combination.

4.2. Informal processes

Informal processes are very determining in relation to whether or not ergonomics is integrated in projects. One of the premises in engineering design is that the engineering designers are in charge of the design job and the design process. From this position they involve the ergonomist when they find it relevant. As a starting point the engineering designers are open towards integrating ergonomics in their design processes and this openness promotes the integration of ergonomics in the design process. Good working relationships between the engineering designers and the ergonomists promote the openness towards integrating ergonomics in the design job. Preliminary dialogues between the engineering designers and the ergonomic professionals also seem to promote the integration of ergonomics in design processes as the preliminary dialogues forms the basis for integrating ergonomics.

Nonetheless the engineering designers only wish to involve the ergonomists to a limited degree in design processes. The ergonomist is not invited to take part in the planned process of user involvement and is not invited to participate in the design process before the basic principles for the design job has been established. The ergonomist only participates in a few of the internal project meetings and appears as being loosely connected to the project. This hampers the possibilities for bringing ergonomic knowledge into action in the design process.

When informal processes are crucial in relation integration ergonomics it becomes person-dependent whether or not the ergonomists are involved in the design jobs and if involved, how many hours are allocated to ergonomics on the project.

4.3. Framing of ergonomic knowledge

There is a framing of the ergonomic knowledge which is brought into action in design processes. The framing is affected both by the engineering designers and the ergonomists opinion on which aspects of ergonomics it makes sense to address in the design jobs. When designing new work places both the ergonomists and the engineering designers find it most relevant to integrate physiological aspects of ergonomics and to a minor degree physical aspects of ergonomics. Within engineering design practice there seems to be a predominant view on work places as "physical container for work processes" and hence more organizational and chemical aspects of ergonomics are not addresses in design processes.

Furthermore the engineering designers regard ergonomics as one discipline: They involve several engineering designers with different engineering expertise, but only a single ergonomist. This limits the possibilities for bringing different areas of ergonomics into the design process.

The ergonomic knowledge which is being brought into play in the design processes is based upon Danish legislation on occupational health and safety and can be characterized as institutionalized ergonomic knowledge.

4.4. Competing criteria

The category competing criteria illustrates that ergonomics is one out of many different aspects with are important in relation to work place design. Other criteria in an engineering design process can for instance be hygiene or financial aspects and these criteria conflict with ergonomics from time to time.

In relation to the overall design process the design actors have to make a decision on whether or not to integrate ergonomics and if they decide to involve an ergonomist to what extent the ergonomist should be involved. This weighing is done in relation to the overall budget of the project.

At the specific design job ergonomic recommendations are weighted in relation for instance hygiene or and financial considerations and whether or not the recommendation makes sense in the given work practice. The weighing is being done without the expertise of an ergonomist. This limits the possibilities for ergonomic considerations being implemented at the new work place.

4.5. Artifacts

"Artifacts" concerns the artifacts which stood out as important in relation to integrating ergonomics in the engineering design processes. In this case the artifacts were:

- An ergonomic guideline document
- Layout sketches

The ergonomic guideline document was created to pass on the ergonomic recommendations given by the ergonomist and in this way promote the integration of ergonomics in the design process. It turns out however that some recommendations were implemented at the new work place, while others were rejected due to "conflicting criteria". Hence ergonomic "packages" in the form of written documents are weak in integrating ergonomic knowledge in the design process.

The layout sketches were used as means to facilitate a dialogue about ergonomics in relation to the design object in question. In this context of use they help to bring ergonomic knowledge into action. The limitations of the layout sketches as means to bring ergonomic knowledge into action are that they contribute to the framing of the work place as a "physical container of work processes". Thereby the sketches influence the framing of the ergonomic knowledge being brought into action in the design process.

4.6. The sales system

The sales system also affects the engineering design practice and the integration of ergonomics into the design process. The category "the sales system" relates to the sale processes the engineering consultancy firm engages in.

The engineering designers are economically in charge of the design processes and have the main contact with the clients. They are in charge of allocating hours to the different members of the design team. This limits the possibility for ergonomists being allocated enough hours to being involved throughout the design process.

In relation to the category "the actors' competencies" it is a hypothesis that the engineering designers do not have the competencies to see when and how it is beneficial to integrate ergonomics in a design process. Thus they do not have the competencies to describe and *sell* to the clients how they can benefit from involving an ergonomist throughout the design process. This is a barrier to the integration of ergonomic knowledge in the design processes.

There is also a problematic elated to "the payment of ergonomics". Who is to pay for integrating ergonomics in design processes, the client or the consultancy firm? It limits the integration of ergonomic knowledge in design processes that it implies extra expenses to involve an ergonomist. With this given it promotes the integration of ergonomics if the client is prepared to pay extra and limits the integration if the client is not prepared to pay for the extra expenses. It promotes the chances of the client paying extra if the client has positive experiences with the ergonomists from the engineering consultancy firm.

4.7. The scope of the design job

This category is closely related to the "the sales system". The scope of the engineering design job was established in a dialogue between the engineering designers and the client. The design team was to complete an extended project proposal and then leave the project, while the hospital themselves were in charge of the implementation and start-up phase of the sterile processing plant. More specifically the scope was to do the logistics and layout of the sterile processing plant. As mention in the category "framing of ergonomic knowledge" mainly the physiological and physical aspects of ergonomics was dealt with in the design process. A different scope like for instance "designing a new department for a sterile

processing plant" might have invited to bring more the organizational aspects of ergonomics into action and also have made it possible for the ergonomist to bring their process-related competencies into action.

A lot of important decisions about the future design of the work place are being made by the client in the implementation phase. It limits the integration of ergonomic knowledge that the engineering design processes do not include the implementation phase. If the engineering designers are contacted to do follow-up on their design solution in the implementation phase they do not contact an ergonomist even when they make decisions that have impact on the working environment. This limits the implementation of ergonomic recommendations at the new work place and limits the value of involving an ergonomist in earlier phases of the design process.

A hypothesis in relation to this is that the engineering designs are not good enough to challenge the client on the scope of the design job and on the decisions the client make during the design process.

5. Discussion

The results show that the integration of ergonomic knowledge into engineering design processes is affected by many different factors.

Table 1 displays factors which promotes the integration of ergonomic knowledge into engineering design processes. The limiting factors identified in section 4 have been turned around and are presented as potential promoting factors in

Table 1.

Table 1

Factors which promote the integration of ergonomic knowledge into design processes

Promoting factors	Potential promoting factors
When the engineering designers identify challenges they consider to be related to ergonomics, such as a lack of space, they are more likely to involve an ergonomist.	Improving the engineering designers' ability to see how and when to integrate ergonomics into the engineering design practice.
The ergonomists knowledge on the work practice outside the scope of the engineering design jobs is appealing to the engineering designers.	Improving the ergonomists knowledge about design processes and their competencies to participate in design processes. For instance learning about the terminology.
Good working relationships between ergonomists and engineering designers promotes openness towards integrating ergonomic knowledge.	Improving the ergonomists competencies to "sell" their organizational and process-related competencies to the engineering designers.
Preliminary dialogues between the engineering designers and the ergonomic professionals about the incoming design jobs promote the chances for ergonomists being involved in projects.	Improving the engineering designers understanding of the many facets of the area of ergonomics.
If the clients are willing to pay for involvement of ergonomists in design jobs it is easier for the engineering designers to balance financial and ergonomic aspects.	Provide organizational structures/strategic decisions which can stem up for the "person-dependent" integration of ergonomics in design processes.
Clients' positive experiences with ergonomists from the engineering consultancy firm promote the clients' willingness to pay extra for the involvement of ergonomists in design jobs.	Providing ergonomic support to the engineering designers and consultants when they have to weigh the ergonomic recommendations against conflicting criteria. This implies the involvement of an ergonomist throughout the design process.
The use of ergonomic "packages" in the form of written documents promotes the integration of ergonomic knowledge when the recommendations do not conflict with other criteria of the given work practice.	Improving the ergonomists ability to argue for the integration ergonomics in design processes and hereby their ability to *sell* how the engineering designers and the clients can benefit from the involvement of ergonomists in projects.
Artifacts used means to facilitate a dialogue about ergonomics in relation to the design object in question helps to bring ergonomic knowledge into action.	Improving the engineering designers' ability to sell ergonomics to clients.
	Discuss internally in the engineering consultancy firm how to handle the fact that it costs extra to involve ergonomist in projects.
	Improving the engineering designers' ability to challenge the clients on the scope of the engineering design jobs.

In order to promote integration of ergonomics into design processes both engineering consultancy firms and ergonomic professionals can work actively with the identified promoting factors and the potential promoting factors.

Within the engineering consultancy firms organizational initiatives can be made to support the promoting factors. Since the completion of the case study the engineering consultancy firm has established formal staffing procedures in order promote

cross disciplinary work. In the light of this study this is an interesting organizational initiative and it would be interesting to access whether or not these formal procedures are able to improve the integration of ergonomics and stem the more random and informal staffing processes. In addition to the formal staffing procedures the engineering consultancy firm could also formalize preliminary meetings between engineering designers and ergonomist when new projects are introduces. Furthermore the engineering consultancy firm could introduce "cross disciplinary forums" where ergonomists and engineering designers can exchange experiences from projects. Hereby both ergonomists and engineering designers can learn about each other's professions, develop competencies in how to integrate ergonomic knowledge into the engineering design practice, establish a foundation for further collaboration *and* develop competencies in how to sell both each other's services and their combined services to their clients. Learning about each other's professions could also improve both the engineering designers and the ergonomists ability to challenge the clients on the scope of the engineering design jobs. Another way to improve this ability is to team up the engineering designers with an ergonomist during the sales processes and to use the contacts and good working relationships the ergonomists have with their clients. Furthermore it would be beneficial to discuss internally in the engineering consultancy firm how to handle the extra costs of integrating ergonomics in projects. One solution is only to integrate ergonomics to the extent the clients are willing to pay. Another solution is to decide that a certain amount of the budget for all projects should go to integrating ergonomics.

Focusing on the individual design job the integration of ergonomics could be improved by involving an ergonomists throughout the different design phases. The purpose of this initiative is to provide ergonomic support to the engineering designers and the clients in situations where different criteria conflicts and hence enhance the chances of the ergonomic recommendations being implemented at the new work place. At the individual project both engineering designers and ergonomists could benefit from carefully considering the use of artifacts to facilitate knowledge sharing.

The ergonomists needs to focus on establishing positive working relationships with the engineering designers and get into a position where they can sell their ergonomic competencies to the engineering designers. To be able to do so the ergonomic professional needs to develop competencies in how to run a design process and get a broader insight into the different challenges of a project manager. The positive relationship with the engineering designers is crucial in relation to getting involved in design processes.

6. Conclusion

The objective of this paper was to uncover how different factors either promote or limit the integration of ergonomic knowledge into design processes.

A model illustrating these different factors was developed and presented along with different hypotheses about how the factors promote and/or limit the integration of ergonomics into design processes.

The model was based on a single case study and this paper calls for further investigations whereby the presented hypotheses can be confirmed or disconfirmed. In the further work with the model it is also interesting to focus on how the different categories are interrelated and to form hypotheses about these interrelations.

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Integrating ergonomics into the engineering design: The role of objects

Lene Bjerg HALL-ANDERSEN[1,2)] and Ole BROBERG[1)]

[1)] *Department of Management Engineering, Technical University of Denmark, Building 424, DK 2800 Lyngby, Denmark*

[2)] *ALECTIA Consulting, Teknikerbyen 34, DK 2830 Virum, Denmark*

Corresponding author:
Lene Bjerg Hall-Andersen
DTU Management Engineering
Produktionstorvet, Building 424
DK 2800 Lyngby
DENMARK
Mobile +45 22 27 04 44
Email lbjso@dtu.dk

Abstract

The objective of this study was to explore the role of objects in integrating ergonomic knowledge in engineering design processes. An engineering design case was analyzed using the theoretical concepts of *boundary objects* and *intermediary objects*: Boundary objects facilitate collaboration between different knowledge domains, while the aim of an intermediary object is to circulate knowledge and thus produce a distant effect. Adjustable layout drawings served as boundary objects and had a positive impact on the dialogue between an ergonomist and designers. An ergonomic guideline document was identified as an intermediary object. However, when the ergonomic guidelines were circulated in the design process, only some of the guidelines were transferred to the design of the sterile processing plant. Based on these findings, recommendations for working with objects in design processes are included.

Keywords: Engineering design; Intermediary objects; Boundary objects

1. Introduction

Integrating ergonomics into engineering design of new workplaces and production systems is believed to be an important pro-active strategy to enhance good working conditions and production efficiency (Broberg, 2010; Dul and Neumann, 2009; Jensen, 2002; Hendrick, 2008; Neumann et al., 2009; Neumann et al., 2006). A widespread approach to integrate ergonomic knowledge in engineering design is to provide the designers with information on ergonomics, through for instance ergonomic standards or handbooks. Studies have however indicated that this approach alone does not ensure successful integration (Broberg, 2007; Burns and Vicente, 1994; Campbell, 1996; Helander 1999; Roger and Armstrong, 1977). Wulff et al. (1999a, 1999b) have studied the integration of ergonomics in large-scale engineering design in the offshore industry in Norway. Here, documents containing ergonomic requirements were distributed within the design organization under the assumption that designers would integrate the requirements in their workspace design. Wulff et al. (1999a, 1999b) found, however, that the requirements were not well known in the design organization, and even when the designers did know the requirements, they were not all integrated into the final design. Some requirements were difficult for the designers to interpret, while others created a situation of conflicting criteria. These findings illustrate possible limitations to using objects like documents to pass on ergonomic knowledge in design processes. However, so far, the human factor (HF) literature has not given much attention to a broader focus on how different objects can help or limit integration of ergonomic knowledge in design processes.

1.1 Theoretical perspectives on objects

Traditionally, engineering designers have viewed objects, such as drawings and prototypes, as neutral: Objects are means of coming from an idea to a result (Vinck et al., 1996). A different view of objects is found within the Science and Technology Studies (STS) tradition. STS has focused on the role of different objects for several years. Objects here are regarded as mediators that can play an active role in design processes (Vinck et al., 1996), and as a result, different theoretical concepts have been developed. The concepts of *boundary objects* and *intermediary objects*, which are presented below, have been used

successfully to create new insights and a greater understanding of the role of objects in design processes (Boujut and Blanco, 2003; Carlile, 2002).

I) The concept of *boundary objects* was introduced in Star and Griesemer's (1989) studies of scientific work. Star and Griesemer (1989) focused on the heterogeneous nature of scientific work and introduced the concept of boundary objects as a way to manage the tension at the boundary between diverse groups of actors. According to Star and Griesemer (1989), different groups of actors belong to different social worlds, and when they work together, boundary objects can help establish a shared context between them that helps create common understanding of the subject in question. The nature of the boundary objects "*is reflected by the fact that they are simultaneously concrete and abstract, specific and general, conventionalized and customized*" (Star and Griesemer, 1989). Carlile (2002) drew on the work of Star and Griesemer and introduced the concept of boundary objects to the area of new product development. He found that objects such as assembly drawings can be useful when cooperating across different knowledge domains in a design process. He identified three characteristics of a useful boundary object: It "*establishes a shared syntax or language for individuals to represent their knowledge*"; secondly, it "*provides a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary*"; and finally, it "*facilitates a process where individuals can jointly transform their knowledge*" (Carlile 2002, p. 451-452). In this paper, we define *boundary objects* as objects that function as mediators in the direct communication between actors.

II) In contrast to the concept of boundary objects, we introduce the concept of *intermediary objects*. These objects are used as a means of transferring and sustaining knowledge, for instance, in a design process, when actors may not be able to meet in person. The concept was developed by Callon (1992), who presented four different types of intermediaries: texts, technical artifacts, human beings and their skills, and money. In this paper, we focus on texts.

An intermediary object is an object produced by a network of designers with the specific intent of *transferring* their knowledge and experience to downstream actors. In

relation to workplace design, the aim of the designers is to affect the final design of the workplace from a distance. An intermediary object, however, creates a new point of departure, and downstream actors might not comply with the intentions embedded in the object: After receiving an intermediary object, downstream actors do not necessarily just transfer the content of the object. When relating the object to their own profession or work practice, downstream actors may ignore or alter different parts of the intermediary object and thus *transform* the content of the intermediary object according to their own interest, purpose or profession (Gherardi and Nicolini, 2000; Vinck et al., 1996). Vinck et al. (1996) address the view and characteristics of intermediary objects by distinguishing between "open" and "closed" objects. This distinction is related *both* to the predominate view of objects as playing either a non-active or active role in design processes *and* to the *interpretive flexibility* of a given object, which is bound to the use of the object. In relation to the focus area of this paper, an example of an intermediary object is an ergonomic standard, which from the outset is produced as a "closed" object intended to transfer knowledge from ergonomists to other design actors. Whether or not the standard succeeds will depend, however, on whether the users interpret the standard as a "closed" or "open" object.

1.2 Objects in HF literature

A few studies in the HF literature draw on the STS tradition and indicate that different kinds of objects can play an important role in integrating ergonomics. In the area of participatory ergonomics, Broberg et al. (2011) find that the characteristics of boundary objects are of great importance in enabling user participation and collaboration in design. One of the important characteristics is *flexible and malleable* objects, as this characteristic creates the possibility to do rapid prototyping of design solutions. In another study, Conceição et al. (2012) develop two intermediary objects, a recommendation booklet and a zoning pattern, in order to transfer ergonomic knowledge and user experience to designers working in the offshore industry. In this industry, face-to-face meetings between users and designers are not always possible, which makes information transfer via objects unavoidable. At workshops with engineering designers, the usability of the two

intermediary objects was evaluated as positive, and they were recommended for use in future design processes. Both studies were based on objects designed by researchers. Objects developed in a 'natural' design process, without the participation of researchers, have not been given much attention in the HF literature so far.

1.3 Aim of the study and use of the concepts

The aim of this study is to provide greater understanding of the role of objects used in 'natural' design processes, where ergonomic knowledge is integrated into engineering design processes. We seek to gain this understanding by applying the concepts of *boundary objects* and *intermediary objects* in an analysis of an engineering design case in which an ergonomist took part in the design process. Both theoretical concepts provide the possibility to enhance understanding of the different roles an object might play during the integration of ergonomic knowledge into engineering design processes.

The paper is concluded by providing implications for both ergonomists and engineering designers.

2. Method

An explorative case study (Thomas, 2011) was carried out in an engineering consultancy firm for the purpose of increasing understanding of the role objects play in the process of integrating ergonomic knowledge in design. We begin by describing the case scenario.

2.1 The setting

An engineering consultancy firm was hired by a hospital to design a sterile processing plant. The design task involved designing the logistics and layout to deliver as a project proposal for the hospital and their building contractor. The design team included engineers with different areas of expertise; a consultant (C1) who was a trained nurse; a project manager (PM) who was an engineer and the head of the hospital division.

The physical space designated for the sterile processing plant was rather cramped; therefore, the project team decided to involve one of the engineering consultancy firm's own ergonomists in the project. The coordinator of the ergonomists' "hospital group" was in charge of selecting the ergonomist to assign to the design job. Based on his experience from other design jobs, he selected a trained physiotherapist. The ergonomist's job was to make sure that the design proposal complied with existing occupational health and safety (OHS) legislation, and to complete an ergonomic guideline document (EGD) with her recommendations for the design.

After the design proposal had been completed and submitted, the hospital contacted the engineering consultancy firm again for assistance during both the construction and start-up phases at the sterile processing plant. At this time, the PM assigned another consultant (C2) from the same consultancy firm to assist the hospital. She was a former manager of a sterile processing plant, and her main job was to support the hospital with overall guidance, help the hospital draw up specification requirements for new equipment, and implement a computer system for stock control. Table 1 illustrates the phases of the design process and the central design actors involved.

Table 1: The design process: Design phases and involvement of central actors

	Analysis	Design	Contracting	Construction	Start-up
Head of Hospital division	X				
Project Manager, PM	X	X		X	(X)
Consultant, C1	X	X			
Ergonomist		(X)			
Consultant, C2				X	X
Manager at the Sterile Processing Plant				X	X

X = involved, (X) = partly involved

2.2 Data collection

The data material was collected over a five-month period through interviews, observation and document study.

Interviews - Twelve semi-structured interviews (Kvale, 1996) were carried out. Purposive sampling (Miles and Huberman, 1994) was used to select whom to interview. We were interested in actors who had been engaged in integrating ergonomic knowledge into the engineering design job. Within the engineering consultancy firm, the interviews included the head of the hospital division, the project manager, two consultants, an ergonomic group leader and two ergonomists. Within the hospital organization, the interviews included the manager of the sterile processing plant, a health and safety representative and two ergonomists. All interviews were audio recorded and afterwards transcribed.

Observation - The first author visited the completed sterile processing plant to observe the design in operation. She observed the users and interviewed four of them while they were working, and identified whether or not the ergonomic recommendations from the EGD had been realized in the final design.

Documents - A study was made of the documents related to the project. The objective was to gain an overview of the design process and understand the degree to which ergonomic issues were discussed at project meetings. The document study involved examining minutes of meetings, project presentations, project plans, drawings, working documents and finally the EGD. Based on these documents, we were able to create a flow chart displaying the progress of the design process.

2.3 Data analysis

Based on an inductive analysis approach (Thomas, 2006), all transcriptions and the selected documents were coded for the theme "written objects used to integrate ergonomic knowledge in the design process". After identifying all text segments related to this theme, we started going back and forth between the data material and the theoretical concepts of *boundary objects* and *intermediary objects.* This iterative process continued throughout the writing process, where the theoretical concept helped us to make sense of the empirical

findings, and the data material helped us to make sure our claims and findings were grounded within the data. The theoretical concepts helped us to gain new insights about how the objects had helped or limited the integration of ergonomic knowledge in the design process.

3. Results

Through thorough analysis of transcriptions and the project documents, it appeared that two objects had played a central role during integration of ergonomic knowledge into the design process: The EGD and layout sketches of the sterile processing plant. The first document we address is the layout sketches.

3.1 The layout sketches

The layout sketches were used at meetings between the ergonomist, C1, and the project manager in their discussions of the future design of the sterile processing plant. The discussions can be characterized as dialogues, where C1 and the project manager presented the ergonomist with their layout suggestions. The ergonomist then commented on the layout sketches and suggested changes, and in this way contributed her knowledge of ergonomics. As described by C1:

> "We had made some sketches with accurate dimensions, and then I explained how much space we had available and how we had placed the tables, and then I asked her [the ergonomist] if it was all right in relation to legislation. We talked back and forth and realized that we had to redo the layout sketches, because it turned out that there was not enough space in the proposal we had made. It was absolutely great that we had involved her [the ergonomist]."

At some meetings, a draftsman also participated and adjusted the layout sketches as new ideas for the layout arose. The ergonomist explained:

> "… I was to relate to the layout proposal and evaluate whether or not the proposal met ergonomic requirements. It was a lot of fun. Sometimes, when we had meetings, a draftsman participated and then we talked through the sketches and had new suggestions. Well, then she [the draftsman] just entered the drawing programs and came back with new sketches right away… That was amazing, because we were able to say 'okay, that part is good, but that means that…'. It worked very well."

The on-the-spot adjustments supported the dialogue and helped to clarify pros and cons of different layout solutions. Based on the layout sketches, the ergonomist, C1 and the project manager addressed a number of issues such as space, glare caused by sun coming through the windows, and noise from washing machines. The layout sketches also helped them address consequences of the different design suggestions and bring forward their different professional viewpoints. Based on these discussions, the layout was adjusted. The version agreed on by all three design actors ended up being the layout that was recommended to the hospital (see Figure 1).

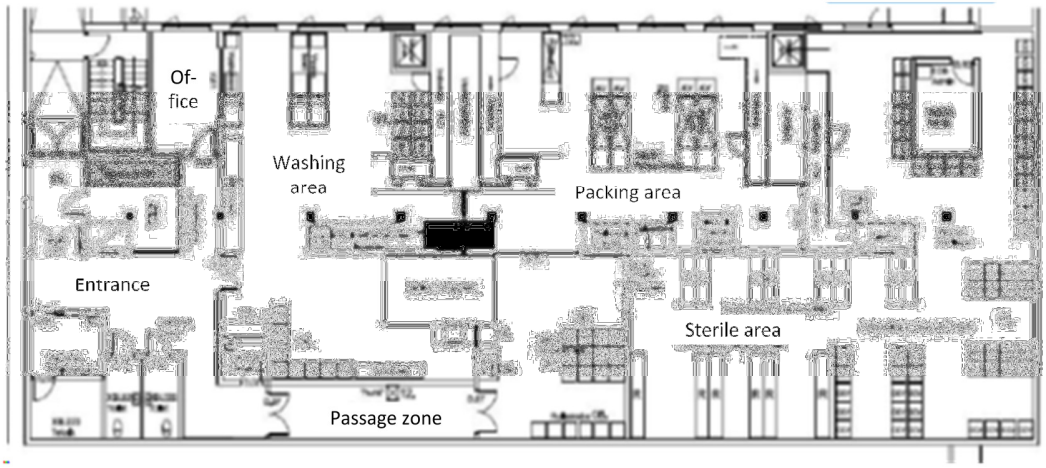

Figure 1: The recommended layout sketch

3.2 The ergonomic guideline document

The development of the EGD was based on the discussions between the ergonomist, C1 and the project manager. As the ergonomist said:

> "It was not enough just to sit there and talk about it at the meeting. It was important to get it in writing as well – all those considerations."

The ergonomist was the main author of the EGD. C1 and the project manager also wrote some paragraphs in the document. The ergonomist also contacted a colleague in the ergonomics department who contributed a paragraph on indoor environment, noise and acoustics to the report. Table 2 presents the content of the EGD.

Table 2 Content of the EGD

Main sections in the document	Contents
1. Introduction	The design task is described in this section.
2. Essential ergonomic issues	The main issues for building projects in general are described as issues related to the physiological and physical aspects of ergonomics.
3. Workrooms	A selected paragraph from a WEA guideline (completed by the Danish Working Environment Authority) is included here.
4. Workplace design	Recommendations on space, walking areas, transportation vehicles, goods lift and equipment (tables, shelving units etc.)
5. Personal protective equipment	Generic recommendations for personal protective equipment
6. Indoor environment and noise	Subjects like temperature, draught, static and acoustics are briefly touched upon.
Appendix	Layout sketch of the recommended layout

The main issues in the document are workplace and workstation design revolving around physiological and physical aspects of ergonomics. The document's recommendations are based on six guidelines issued by the Danish Working Environment

Authority (WEA). WEA is an agency under the Danish Ministry of Employment and has the authority to draw up rules on occupational health and safety (OHS), provide information about OHS and carry out inspections of companies. The WEA guidelines are all "easy-to-understand" guides for grasping legislation on OHS and workplace design in Denmark.

In some paragraphs of the EGD, the ergonomist quoted the WEA guidelines verbatim, and in other paragraphs, she translated the guidelines and related them to the work practice she expected at the sterile processing plant. Throughout the EGD, the ergonomist also referred to the layout sketch, which is presented in the document's appendix. Focusing on the formulations in the EGD, we found that more than half of the recommendations were generally or vaguely formulated, using such phrases as: "*…as much as possible*" or "*there should be…*". An example of one of the specifically formulated recommendations in the document is: "*All workstations must have daylight access*". There were also recommendations where specific measures for recommended distances were given.

After having completed the EGD, the ergonomist handed it over to C1 and the project manager. She then left the project. C1 and the project manager then circulated the EGD, including the layout sketch, to actors in the hospital organization and to the hospital's turnkey contractor. At the hospital, the EGD was given to the manager of the technical department, the manager of the sterile processing plant, a health and safety representative and an ergonomist. The EGD was also given to C2, who used the EGD in her consultancy work.

3.3 The completed plant

When the first author visited the sterile processing plant, the plant was still in the start-up phase and had been running on and off for six months. Observations and interviews with employees revealed that they were pleased with some aspects, but they also experienced problems in a number of areas. Comparing the recommended layout and recommendations in the EGD with the actual layout and work practice in the sterile processing plant showed that some of the recommendations had been complied with, while

others had not. In Table 3, the main recommendations are related to the findings in the sterile processing plant.

Table 3: Findings in the sterile processing plant

Recommendations in the EGD	**The completed plant**	
	Observations	**Employee evaluation**
Space and layout		
- Enough space to establish safe and sound work processes. Min. 110 cm free space behind tables.	- In the packing area the 110 cm are not complied with for all tables. This was decided in order to enhance a better work flow.	- There is a lack of space in the packing area, which results in undesirable twists when moving around with equipment.
Daylight		
-All stationary workstations must have daylight access. - Gaze direction should be parallel with windows to prevent glare from the sun.	- Workstations in the sterile stockroom have no daylight access. - Three of the packing tables were not placed parallel with the windows and created a potential risk of glare from the sun.	- Generally very pleased with the amount of daylight.
Shelving units		
- The employees should be able to pass a transportation vehicle or trolley unhindered between the shelving units. 140 cm between the shelving units is incorporated in the layout.	- Movable shelving units had floor mounted rail that made it hard to cross with trolleys. There was also a risk of being trapped between moving units. The 140 cm between the shelving units was not complied with due to lack of storage space.	- The main activity in the sterile area was to pack equipment. It was very unpleasant with the movable units. If a colleague did not see you standing between the units, they might start to move the units, and then you would have to yell in order not to get trapped between them.
Transportation		
- Due to a slope in the floor, self-propelled vehicle device was recommended in the tunnel. Moving traffic should also be separated from walking traffic and properly marked.	- Deselected due to a lot of walking traffic and for financial reasons, and there were no marking separating the movable traffic from the walking traffic.	- One employee stated that the transportation vehicles were too heavy. The daily leader planned to hire a hospital porter to handle the heavy vehicles.
Equipment		
- Equipment must be height adjustable.	- All washing tables, packing tables, EDP workstations, chairs and some transportation vehicles were height adjustable.	- The employees were very satisfied with the height adjustable equipment.

- The vehicles must be equipped with handles.	- Not implemented	
- Transportation equipment and load must not limit the view of the employees.	- (Not observed in operation)	- Some employees were too short to see over the largest transportation vehicles.
Floor		
- The floor must be of anti-slip materiel and the hardness must be appropriate, so it is not tiring to stand and walk on.	- The materiel is anti-slip, and the floor is made in a special way that should make it appropriate.	- Many employees complained about the hardness of the floor, which results in pain in feet, knees and back.
- Stationary workstations should have shock-absorbing mats.	- The daily leader was looking for appropriate mats.	

Interviews with C2 and the daily leader at the sterile processing plant indicated why some of the recommendations were not transferred to the final design. For example, it was recommended that the transportation vehicles be equipped with handles, but in the specification requirement for the transportation vehicle, the handles were not included:

> C2: "There are no handles. [The hospital] distinctly deselected the handles. They don't make sense. They are extra, take up space, and they would mean that there would be room for fewer vehicles in the lift. And no matter whether you are short or tall, you can just push by, holding on to the racks of the vehicle.
> Interviewer: "So someone has simply deselected the handles?"
> C2: "I participated… …I have made all the specification requirements."
> Interviewer: "Did you contact an ergonomist who then said, 'yes, with or without the handles – that doesn't really make a difference'?"
> C2: "No that is a judgment we made. You know, it's not just about ergonomics. It also has to do with finance."

Considerations of both financial aspects and overall efficiency of work practice were used as arguments for not including recommendations the specification requirement. Another example is related to a recommendation to implement a self-propelled vehicle for transportation to and from the sterile processing plant, due to a slope in the floor in a

tunnel connected to the sterile processing plant. C2 argued that the recommendation did not make sense:

> C2: "It is an extremely expensive solution… Well, actually, I think it is fine to recommend it…. To me the recommendation says that when a vehicle has been packed, then it should be placed on a robot, which then takes it to the sterile processing plant and drops it off.... I think it sounds reasonable, but can you imagine… a robot going down that aisle with all those cabinets and people going back and forth…. The robot would have to stop a hundred times…. It wouldn't work, really…. At least, I think that's what it means – without really knowing for sure…."

In this example, the ergonomist's recommendation for a self-propelled vehicle is interpreted by C2 as a robot and consequently rejected as being unworkable and too expensive. A follow-up interview with the ergonomist revealed, however, that she never intended to recommend a robot. Rather, her recommendation was a transportation vehicle with an electric motor that created propulsion, but would be steered by the employees.

Interviews and observations also revealed that there were issues related to the working environment that were not addressed in the EGD. For example, the sterile processing plant's employees and daily leader experienced problems related to the psychosocial working environment during the start-up phase, when a whole new group of employees were brought together; they also became aware that many chemical issues needed to be considered; and they experienced communication problems with the surgery units. Also, there was no break room for the employees.

4. Discussion

In the following, we mobilize the theoretical concepts by relating them to the findings presented above in order to illuminate how the objects played a role in integrating ergonomics in the design process.

4.1 The layout sketches

During the meetings between the ergonomist, C1, and the project manager, the layout sketches served as boundary objects. They helped facilitate a constructive dialogue between the three actors, and helped make the design object more tangible. Drawing on Carlile's (2002) characteristics of an effective boundary object, we find that the layout sketches were able to establish "*a shared syntax or language*" (Carlile 2002, p. 451-452) across the different knowledge domains, and this enabled the ergonomist to contribute with her professional knowledge. With the layout sketches placed in the middle, the three actors were able to discuss the pros and cons of different solutions. During these discussions, they "*learned about their differences and dependencies*" (Carlile 2002, p. 451-452): The project manager contributed with knowledge on engineering design; C1 contributed with her practical knowledge about the work processes and flow in a sterile processing plant; and the ergonomist contributed her knowledge on ergonomics and the Danish OHS legislation. Even though they were not able to fully understand each other's work practice, they were able to complement each other. The layout sketches facilitated this process and enabled the actors to "*jointly transform their knowledge*" (Carlile, 2002, p. 451-452) and their professional views into a layout. The ergonomist's involvement led to changes in the layout (tables etc. were moved), and through dialogue. the three actors were able to come up with a layout they could jointly recommend.

Using the layout sketches as a boundary object helped to integrate ergonomic knowledge into the engineering design process, but the study also revealed some limitations. The ergonomist explained that she was especially fond of the meetings where a draftsman participated. We can address this finding by applying the distinction between 'open' and 'closed' objects (Vinck et al., 1996). The draftsman's involvement in the meetings created an 'open' boundary object, because the draftsman was able to make changes in the layout as the dialogue unfolded. This enabled C1, the ergonomist and the project manager to explore and elaborate different solutions during the meetings. When the draftsman did not participate, the dialogue between the three actors was based on a "traditional layout sketch", which constitutes a 'closed' boundary object. They were able to discuss the presented solution, but they were not able to make on-the-spot changes and

thereby clarify pros and cons. Broberg et al. (2011) also draw on the distinction between open and closed objects and argue that an open object allows a transformation of the object, which enables participants to *design with* the objects.

When the final layout was agreed upon, it was handed over to the hospital and its construction contractor. The role of the layout sketch now changed from being a boundary object to being an intermediary object. The layout sketch communicated the recommended layout to the downstream actors in process. This can be seen as an attempt to produce a distant effect on the sterile processing plant's layout. The downstream actors were supposed to transfer the recommended layout, including the ergonomic recommendations embedded in the layout sketches. However, as presented in the result section, adjustments were made to the packing area and the sterile area. Evidently, the design process was continued during the implementation of the recommended layout, and as an intermediary object, the layout sketch was not able to perform a distant effect on all areas of the sterile processing plant.

4.2 The ergonomic guideline document

In the EGD, the ergonomist stated recommendations for the future design of the sterile processing plant. The intent of the document was to pass on ergonomic knowledge to the further design process. This can be seen as an attempt to produce a distant effect, since the ergonomist did not participate in the remaining design phases in person. However, the document was not able to perform the full distant effect the project team had hoped for. Some of the recommendations were *transferred* to the design of the sterile processing plant, while others were *transformed*. Furthermore, some ergonomic aspects had not been addressed in the document. These findings indicate that using an EGD to pass on ergonomic knowledge in a design process has some limitations. This is also indicated in studies like Burns and Vicente (1994) and Burns et al. (1997) on ergonomic information transfer in design.

In the following, we address the findings in this study, and, guided by the concept of intermediary object, we focus on the role of the EGD – first by focusing on the framing of

the ergonomic knowledge in the EGD and the network participating in making the document; and subsequently, by analyzing why some guidelines in the document were transferred, while others were transformed.

4.2.1 The framing of ergonomic knowledge in the ergonomic guideline document

The actors who participated in making the EGD wanted to create a sterile processing plant with a safe and sound working environment that complied with existing legislation on OHS. The content of the EGD reveals that not all aspects of ergonomics were addressed. A framing of ergonomic knowledge had taken place, and only areas related to the physiological aspects – and to a minor degree, the physical aspects – of ergonomics were addressed in the document. Issues related to psychosocial or chemical aspects were not addressed. Our attention in the analysis was now directed to the network participating in making the document, and we found that the framing of the ergonomic knowledge had begun even before the ergonomist had entered the project. The engineering design team was hired to design the layout and logistics of the sterile processing plant. With this scope, the design team's focus was capacity analysis, layout of the sterile processing plant, and flow of the future work processes. This scope of the design job indicates that the predominant view of the sterile processing plant was of a physical container for work processes. This view was also found among the ergonomists involved in the design job: a physiotherapist was assigned and only the physiological and physical aspects of ergonomics were addressed and passed on to the further design process. We argue that a different scope of the engineering design job – for instance, to design a new department for sterile processing – might have created an opening towards integrating more organizational/psychosocial aspects of ergonomics. Using layout sketches as a boundary object may have contributed to the framing, since the interviews revealed that the layout sketches primarily encouraged input and suggestions related to the physical set-up of the sterile processing plant. The appointment of a physiotherapist may also have contributed to the specific ergonomic framing around physiological and physical aspects.

We also identified a great deal of focus on legislation in the EGD. Throughout the EGD, the ergonomist based her recommendations on the WEA guidelines. By referring to these guidelines, the ergonomist drew on the ergonomic knowledge of the different networks that participated over time in making the WEA guidelines *and* in developing the OHS legislation. Hence, the ergonomic knowledge mobilized by the ergonomist is institutionalized ergonomic knowledge, and her references to the WEA guidelines can be seen as an attempt to make the document more powerful and increase its chances of producing a distant effect on the further design process.

4.2.2 Transformation of the guidelines

The main arguments given for disregarding guidelines were related to either cost, hygiene, space or efficiency of the workplace. This finding is in line with Wulff et al. (1999b), who also found time and costs to be the main constraints in relation to implementation of ergonomic recommendations.

We found that the guidelines were transformed when they did not make sense within the downstream actors' rationale. When discussing the guidelines with C2, she often stated that something did not make any sense – for example, the handles for the transportation vehicles. This can be explained through the notion of "social worlds" as put forth in the work of Star and Griesemer (1989) and Garrety and Badham (1999). Actors from different disciplines come from different social worlds; thus, they have different ways of seeing the design object in question, which can create a semantic mismatch. When recommendations are solely based on a guideline document, they may be *transformed* in the processes of *translation,* despite references given to the WEA guidelines. We also identified the example where a guideline was rejected due to a misinterpretation: The notion self-propelled vehicle was interpreted as a robot, which was viewed as unworkable. The document failed to elaborate or explain the underlying rationale and intentions behind this guideline. Based on these findings, we support Wulff et al. (1999b), who found that a problem of using "health and safety documents" to pass on ergonomic knowledge is that the documents do not make clear how to optimize when different criteria conflict - and is not able to catch any misinterpretations, we might add.

Other authors have found that recommendations in ergonomic standards are often ignored, due to vague or general formulations (Broberg, 2007; Burns et al, 1997; Roger and Armstrong, 1977; Wulff et al., 1999a; Wulff et al., 1999b). Wulff et al. (1999a, 1999b) find that generally formulated recommendations leave the designer with a translation problem of how to transfer a general recommendation to a specific design solution. They suggest that ergonomic criteria should be formulated as specific requirements. Relating this to the distinction between open and closed objects introduced by Vinck et al. (1996), the suggestion can be seen as an attempt to create a 'more' closed object.

We found that some of the specific recommendations were transferred to the sterile processing plant, while others were transformed. The same was true for the general recommendations. Both the specifically and the generally formulated guidelines in the EGD seemed to be interpreted as 'open' recommendations - and not as 'closed' requirements that had to be complied with.

4.2.3 Limitations in the use and design of the guideline document

The above finding directs our attention to the intermediary object itself, and indicates that a written object, like the EGD, has limitations beyond the formulations of the guidelines. The EGD was created as a 'closed' object with specific focus on passing on ergonomic guidelines in the design process, but even so, downstream actors experienced a freedom of use and regarded the document as 'open'. There seems to be an embedded flexibility in the EGD in relation to the use of guideline documents per se, and there also appears to be limitations related to the *design* of the document. Burns et al. (1997) studied interfaces between research literature and designers and argued that the design of intermediaries should be based on the characteristics of designers and the constraints of the environment in which the guidelines are supposed to be used. If too little attention is paid to this matter, the guidelines might not be used. We did not find any evidence showing that C1, the ergonomist and the project manager had given any thought to what kind of obstacles the document might meet in the further design process and how these obstacles could be overcome. In line with Wulff et al. (1999a, 1999b) and Conceição et al. (2012),

we argue that the use of written objects to transfer ergonomic knowledge in design processes needs to be supported by organizational initiatives – for instance, by establishing a hotline for ergonomic support when designers experience conflicting criteria, or through involvement of an ergonomist throughout the design process.

4.3 Limitations of the case study

A single-case study was chosen, since the aim of the study was to explore and gain in-depth understanding of the role of written objects in integrating ergonomics in engineering design processes. The limitation of a single-case study, however, is that the findings cannot be generalized to a larger population (Thomas, 2011).

The case study was also conducted retrospectively. Doing a case study retrospectively implies interviewing people about incidents in the past. In some cases, the interviewee had problems remembering what really happened in the design process. The interviewee might also have a 'selective memory'. For instance, they might retell the case in the way they remember it, but this may not necessarily be how the case actually unfolded. Another limitation is that two of those interviewed left the engineering consultancy firm during the period of data collection, which limited the possibility to do follow-up interviews. For further research, it would be interesting to make a longitudinal study where it would be possible to observe a design team during design situations.

5. Concluding Remarks

We argue that objects can play an important and often unrecognized role in the integration of ergonomic knowledge in a design process. In the role of a boundary object, layout sketches, particularly when they were 'open', helped to facilitate dialogue between the involved actors and bring ergonomic knowledge into action in the design process. In the role of an intermediary object, the EGD was intended to transfer ergonomic knowledge to other actors in the design process. The study shows, however, that the EGD had some limitations in fulfilling this role. When downstream actors experienced a conflict between a guideline and other design criteria, the document was not able to enter into a negotiation process and elaborate or explain the underlying reasons for the ergonomic guideline. As a

consequence, some of the given ergonomic guidelines were transformed by downstream actors. Finally, the study also shows that throughout a design process the same object may have different roles and function both as a boundary object in direct communication between involved actors and as an intermediary object that functions as a means of transferring ergonomic knowledge to downstream actors in the design process.

Implications

This study suggests the following implications for practitioners:

- When ergonomists and engineering designers plan to integrate ergonomic aspects in design processes, they should discuss and map how objects, like texts, drawings, and spaces, can help integrate ergonomic knowledge.

- The identified objects should be classified as either boundary or intermediary objects (or both) in order to better understand the potential role they might play in integrating ergonomic knowledge, and which other initiatives might be needed to support the integration.

- Boundary objects that are open for 'on-the-spot' visualization of different design possibilities are better at supporting dialogue between the ergonomist and engineering designers.

- Much attention should be paid to the design of intermediary objects, which are aimed at circulating ergonomic knowledge and guidelines in a design process.

- Ergonomists should consider the framing of the ergonomic issues addressed in the intermediary object. The ergonomic issues that are important to address may vary depending on the scope of the design task, the design process and the organizational context.

- When engaging in the design of an intermediary object, ergonomists and engineering designers need to look ahead in the design process and consider what kind of obstacles the intermediary object could meet on its way, and evaluate how these might be overcome – for example, by including the aim or reasoning behind the guidelines in order to support downstream actors if different design criteria prove to be conflicting.

- Intermediary objects aimed at integrating ergonomic knowledge into a design process may not be able to produce a distant effect for all the intended areas. Therefore, from the outset, both the ergonomist and engineering designers should consider how to arrange for follow-up dialogues during the design, construction, and implementation processes, where decisions affecting work conditions are also made.

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Integrating ergonomic knowledge into business-driven design projects: The shaping of resource constraints

Lene Bjerg HALL-ANDERSEN,[1,2)] W. Patrick NEUMANN[3)] and Ole BROBERG[1)]

[1)] *Department of Management Engineering, Technical University of Denmark, Building 424, DK-2800 Lyngby, Denmark*

[2)] *ALECTIA Consulting, Teknikerbyen 34, DK-2830 Virum, Denmark*

[3)] *Department of Mechanical and Industrial Engineering, Ryerson University, 350 Victoria St., Toronto, ON, Canada M5B 2K3*

Corresponding author:
Lene Bjerg Hall-Andersen
DTU Management Engineering
Produktionstorvet, Building 424
DK 2800 Lyngby
DENMARK
Mobile +45 22 27 04 44
Email lbjso@dtu.dk

Abstract

This study explores how resources can pose constraints for the integration of ergonomic knowledge into engineering design processes in a business-driven setting, and how ergonomists cope with these resource constraints. A case study in an engineering consultancy was conducted, where 27 participants were interviewed. Based on an inductive analysis findings suggest that resource constraint was shaped by factors such as a constant focus on maximizing project revenue and challenges related to payment for ergonomic services. We hypothesize that in engineering consultancies, resources are not evaluated in the full lifecycle of designed work systems. An almost impermeable division between design and operation costs exists and causes a sub-optimization of the resources during design. This sub-optimization clashes with the value of integrating ergonomics in design. This constraint is reinforced by ergonomist's lack of accountability for cost benefit of integrating ergonomics in design. The study also suggests that possibilities to integrate ergonomic skills in design projects can be largely linked to the ergonomic ambitions of the clients and the ergonomist's ability to act in design.

Relevance to industry: The article contributes to understanding the possibilities and barriers in relation to integrating ergonomic knowledge into design, and especially in business-driven design settings. This understanding can help ergonomists and consultancies to cope with and develop strategies for promoting ergonomic initiatives in similar settings.

Keywords: Engineering Consultancy; Engineering Design; Resources; Organizational Design and Management

1. Introduction

Although the integration of ergonomic knowledge in engineering has been shown to lead to both more healthy and effective designs of workplaces (Goggings at al., 2008; Neumann and Dul, 2010; Oxenburgh et al., 2004), little research has been conducted on integrating ergonomic knowledge into the design practice in engineering consultancies, a common setting for engineering design. In this paper, we report on a case study in an engineering consultancy firm, which during 2006-2007 acquired three different occupational health and safety (OHS) consultancies to broaden their line of consultancy services. Design tasks undertaken here are carried out in a client-consultant setting and can be characterized as business-driven: Engineering consultancies engage in design to provide a service for a client *and* to generate a profit in the consultancy. We found that the integration of ergonomic knowledge into this business-driven design context was constrained by an aspect of resources. The term 'resources' refers to the employee hours used and money needed to carry out a service for a client; for instance, provide engineering or ergonomic consultancy services in a design task. In this paper,

we shed a light on what shapes these resource constraints in a setting where the entire revenue is based solely on consultancy services. We focus specifically on ergonomic knowledge in the form of ergonomic services provided by the engineering consultancy's own ergonomists, and identify how the ergonomists cope with resource constraints. We conclude by hypothesizing on how ergonomics can be integrated into engineering design tasks undertaken in business-driven design settings.

Previous studies show that resources can constitute a constraint for ergonomic initiatives. With regard to participatory ergonomics (PE), Eerd et al. (2010) conducted a literature review that concluded that resources were one of the most reported factors influencing success in PE initiatives. Studies of ergonomic interventions also identify resource allocation to be a barrier for the implementation of ergonomic activities (Kirwan, 2003; Whysall et al., 2006). Kirwan (2003) found that even though management was willing to invest in ergonomic activities, it constantly demanded that benefits gained from ergonomic initiatives be accounted for, a pattern that had been previously discussed by Perrow (1983). However, researchers have only given minor attention to the role of resources when involving ergonomists in design.

Bruseberg (2008) accounts for the value of ergonomic contributions in design. She finds that ergonomic activities are often given low priority when budgets are made, and that this can be linked to the view that ergonomic activities are costly. Waterson and Kolose (2010) report similar findings. An often discussed challenge among ergonomists is to argue for the cost benefits of ergonomic initiatives (Beevis, 2003; Beevis and Slade, 2003; Bruseberg, 2008; Kirwan, 2000, 2003; Meister, 1982a, 1982b). These challenges are often linked to the intangible benefits of ergonomics (Beevis and Slade, 2003; Bruseberg, 2008) and the hidden nature of the costs of employees' ill health (Rose et al., 2013). Studies of the offshore industry also reveal that such issues as time, space and costs can constitute constraints for the implementation of ergonomic design criteria in design solutions (Wulff et al., 1999a, 1999b). Béguin (2011) and Haslegrave and Holmes (1994) also pointed to resources, in the form of time and money, as constraints in design processes. Little is known, however, about what shapes these resource constraints in engineering consultancy settings.

In the present study, we explore how resources are shaped as a constraint in a "natural" design context in an engineering consultancy, without the researcher being directly involved. The purpose of the paper is twofold: (1) to explore the shaping of the resource constraints, and (2) to gain knowledge about how ergonomists cope with the resource constraints. The paper begins by introducing the research setting and methods. Subsequently, the different constituents of the resource constraints are presented, followed by a discussion of the findings.

This discussion concludes by hypothesizing about how the involvement of the ergonomic profession can be promoted in a business-driven design setting.

2. Setting

Due to a political decision in Denmark, public funding for occupational health and safety (OHS) services was phased out during the period from 2005 to 2008. This created a new market situation, since OHS services now had to compete on the private market. During the same period, many of the larger engineering consultancies in Denmark established ergonomic/OHS departments within their organizations. The setting for the present study is an engineering consultancy, which during the period from 2006 to 2007 acquired three different OHS consultancies. This consultancy delivered engineering services to a range of different business areas, such as hospitals, dairies, breweries, pharmaceutical producers, food producers and universities. The rationale for the acquiring the OHS consultancies was based on a desire to have a greater palette of competencies with which to access the market, and to be able to offer OHS services to clients after design project were completed. The CEO at the time explained that her ambition was to be able to integrate ergonomic services into design projects in order to increase the quality of the projects. All along, however, the main strategy for the OHS departments was that they should be independently profitable, aside from the engineering design tasks, by selling more traditional ergonomic services. No resources were earmarked for integrating ergonomic services into the design process. At the time of the study, due to these acquisitions, the consultancy firm was in a phase of transition. No formal processes had been set up for how to integrate the ergonomic skills into the engineering design processes, and both ergonomists and engineering designers were inexperienced in working together on projects. Activities were developing aiming at integrating the newly acquired ergonomic skills in the engineering design processes, and this was happening from different actors and different locations in the organization. This study is therefore carried out at a 'formative' point in time as the ergonomists start working alongside engineers in the design projects.

3. Method

According to Thomas (2011), an explorative case study is appropriate when the objective is to generate in-depth understanding. Yin (2009) operates with four different types of designs for case studies (Table 1).

Table 1: Yin's (2009) four basic types of designs for case studies (adapted from Yin, 2009)

	Single-case design	Multiple-case designs
Holistic (single-unit analysis)	Type 1 Single-case (holistic) design	Type 3 Multiple-case (holistic) design
Embedded (multiple units of analysis)	Type 2 Single-case (embedded) design	Type 4 Multiple-case (embedded) design

In this study, a single embedded case study was carried out in the engineering consultancy, where attention was directed toward both the overall case study (the engineering consultancy) and the three embedded design projects in the consultancy firm where ergonomists were involved in the design task. This type of study was chosen because the interest in the phenomenon being studied was two-sided: We wished to gain a better understanding of resource constraints at both the organizational level of the engineering consultancy firm *and* on the design project level.

The study was conducted in a 'natural' design context, without researchers being directly involved in the design process. The primary data source was interviews, which were supplemented by observation and document studies. The method can be characterized as a 'natural experiment', where the experimental conditions were outside the control of the researchers. We studied how actors in the engineering consultancy handled the integration of ergonomic knowledge into the engineering design projects after the engineering consultancy took over the OHS consultancies and physically placed the ergonomist at the same locations as the engineering designers.

3.1 *Case selection*

Both the overall case unit and the embedded cases were chosen on the basis of "purposive sampling"(Miles and Huberman, 1994), where the selection criteria were information-oriented, since we searched "typical" cases: For the overall case company, we wanted to find an engineering consultancy firm with in house ergonomic competencies. For the embedded case units, we looked for projects where ergonomic knowledge had been involved in the design process or were about to be integrated. The selected case units are 1) the design of a sterile processing plant, 2) a conceptual design plan for a seafood company, and 3) the design of a hospital. See Table 2 for case characteristics.

Table 2: characteristics of the design cases (PM= Project Manager, ED= engineering designer)

Case characteristics	Sterile processing plant	Seafood company	Hospital project
The design project	Detailed project proposal incl. layout and logistics.	Conceptual design plan comprising a screening of the current situation in the seafood company and recommendations for future development, incl. conceptual layout plan for one factory.	A new building project involving consultancy in all design phases.
Motivation for integrating ergonomics	The ergonomic department had been consulting at the hospital for years. The hospital and the PM thought it would be a good idea to involve an ergonomist.	The PM and a leading manager in the ergonomic department teamed up in the sales stage and sold ergonomics into the project contract.	Ergonomics was addressed in the sales material for the architecture competition. This was an opening to involve ergonomists in the project.
Participants	- PM: engineering designer - EDs with different backgrounds - An ergonomist	- PM: engineering designer - EDs with different backgrounds - An ergonomist	A consortium working together and consisting of - Two architectural firms - Three engineering consultancies (incl. ergonomists) - Three sub-consultancies
Involvement of ergonomists	An ergonomist involved in part of the design process through: - A visit to the future locations - Layout meetings - A project meeting	An ergonomist involved in the project through: - Trips to the client's factories - a meeting with providers - Various project meetings	Several ergonomists were engaged throughout the design processes through: - More than 400 'user meeting' - Responsibility for design lab and full scale mock ups - Various project meetings - Continuous dialogues
Ergonomic deliverables	- An ergonomic guideline document to feed into the further design process - Recommendations included in the final layout sketch	- An individual ergonomic assessment report for each of the four factories - Inputs such as cost estimates and ergonomic assessments for the structural analysis report - Minor inputs for the master plan	- A room-specific database - A health and safety policy - An ergonomic requirement list, which due to resistance changed name to a recommendation list - An agreement that engineering designers and architects should seek ergonomic support if recommendations were hard to meet
Data collection	- Retrospectively - Interviews N=10, - Document study - To a minor degree observation	- Ongoing project - Interviews N=3 - Observation - Document study	- Ongoing project - Interviews N=6 - To a minor degree observation - To a minor degree document study
Data collection period	- Oct. 2009 to March 2010	- Nov. 2009 to Jan. 2010	- Oct. 2009 and - May 2012 to July 2012

3.2 Data collection

Interviews – A total of 23 persons were interviewed in the engineering consultancy firm: CEOs (N=2), ergonomists (N=10) and engineering design actors (engineers N=6, nurses N=2,

other professions N=2). Furthermore, in the case of the sterile processing plant, two interviews were carried out in the client organization: two ergonomists, a health and safety representative and a manager were interviewed to gain insights on how they experienced the particular case project and whether or not the ergonomic input made it into the actual design of the sterile processing plant. In all three embedded cases, both engineering designers and ergonomists were interviewed to ensure a variety of perspectives. All interviews were semi-structured (Kvale, 2004) and open-ended. The interview guides were modified during the course of the interviews as new insights arose and different actors were interviewed. The interviews were carried out face-to-face and varied in length from 30 to 120 minutes. They were audio-recorded and all essential parts were transcribed. There were three exceptions where interviewees did not wish to be audio-recorded, and in one incident where no audio-recorder was available. More informal ethnographic interviews (Spradley, 1979) were also a part of the data material.

Observations – Data collection stretched over a time period of three years from 2009-2012. During this period, the first author spent approximately two working days per week in the engineering consultancy firm, the first two years in an engineering department and the last year in an ergonomic department. This allowed informal interactions. Field notes were made whenever anything related to the subject of interest was experienced.

3.3 Data analysis

The data analysis was based on an inductive approach (Thomas, 2006). Based on several close readings of the transcribed interviews and field notes, the first author systematically coded the data material in categories. The coding process was inspired by the "constant comparative method"(Glaser and Strauss, 1967), p. 101-115), where coding and analysis processes are combined to allow categories/theory to emerge from data. In this process, all categories were labeled on the basis of interpretations of data material, and in accordance with Thomas (2006), all contradictory point of views or findings were included in the categories. Through constantly comparing incidents and rearranging the different categories, new and more saturated categories emerged. The coding and analysis process was supported by discussions and dialogues between all three authors, and memos were kept in a separate file to grasp different ideas and categories. The coding activities resulted in the following categories adding up to the overall category of "resource constraints": "maximizing project revenue", "payment for ergonomic services", "the value of ergonomic services", "the role of the client" and "coping and forming strategies to overcome resource constraints". The inductive method was concluded by summing up the categories. The categories are presented in the following result section.

4 Results

In the following, we account for the main elements that shaped the resource constraints and report on how ergonomists coped with these constraints.

4.1 Maximizing project revenue

Maximizing the revenue from projects was a major barrier for the ergonomists' involvement in the projects. This was one of the focus points in the consultancy's performance measurement system. An identified condition was that the engineering designers had the role of being PMs and salespersons. In this role, they were in charge of the design projects, which included staffing, resource allocation and balancing budgets. Both engineering designers and ergonomists frequently reported that financial aspects governed whether or not ergonomists were involved in projects.

> ED: "In projects where we are extremely pressed, we might consider whether to spend a day on an ergonomist or whether the financial aspects weighed more…"
> Ergonomist: "We really want to be a part of projects, but even though a wish exists to include ergonomics, it is the last area that receives any resources. As a result, financial aspects often govern whether we are involved or not."
> Ergonomist: "We [the ergonomists] are looked upon as tax… and many [project managers] think: 'This time I will not pay tax'."

Once a project had been initiated, the engineering designers' focus was to deliver the product agreed upon to the client, and at the same time minimize the costs in order to maximize the project revenue.

> PM: "There is one total budget and this [allocating more money for ergonomics] means that there is less money for something else. … It is the usual fight in all projects. If I was an ergonomist, I would argue differently and say that ergonomics is the most important aspect in the project, and that's the way it should be…"
> ED: "There is always a time discussion in the house [in the engineering consultancy firm]. I might say, 'We have to make this tender, do you want to join?' 'Yes, I need 25 hours'. … Who should pay for that? Then, the whole discussion starts and somebody will say: 'That's a burden on my project. Maybe we should just do it alone, because then I get a better factor [revenue of the project)'. These factor discussions are probably not promoting this [the integration of ergonomics in design projects]."

The ergonomists typically experienced a fight to gain resources and used rhetoric like: "The allocated hours were very limited"; "there are many small kings who do not want to give away

hours"; and "they fought until blood was running in the streets". Many of the ergonomists also experienced time pressure when involved in design tasks. The experienced time pressure was due to the limited amount of resources for ergonomic counseling (time to visit the workspace, talk to users etc.); short deadlines tor the design tasks; and ergonomists being engaged in several other traditional (and smaller) ergonomic tasks at the same time. Only one ergonomist did not talk about resource allocation as a constraint in the project he had been involved in. In the case of the seafood project, he felt that ergonomics had been prioritized in line with the different engineering areas of expertise. A special circumstance in this project was that the client had agreed to allocate extra money for an ergonomist to participate in the design job.

4.2 Payment for ergonomic services

A dilemma revolved around whether to include the ergonomic services in the overall price of projects or to sell it as an extra service. Including ergonomic services in the overall price of projects was not seen as a suitable strategy. If the overall price of projects was increased, it would be harder to compete on price. Both ergonomists and engineering designers reported that the best option would be to sell ergonomics as an extra service; however, this solution was not without challenges. In Denmark, all new buildings and production facilities must comply with existing OHS legislation. This rule constituted a dilemma in the consultancy firm, because all design tasks the consultancy firm engaged in had to live up to OHS legislation – with or without the involvement of ergonomists. Both ergonomists and engineering designers reported that they found it difficult to meet this challenge.

> Business unit manager: "We cannot just add it [OHS] to the bill, because we are already saying we are doing that, just without the involvement of ergonomists."
> Ergonomic manager: "Some clients will say: 'Well, you have to live up to the OHS legislation in the services you deliver. What do we get extra?'"

4.3 The value of ergonomic services

The integration of ergonomic services was constrained by the engineering designers' doubt about the cost benefits of the ergonomic contributions and the ergonomists' reluctance to go into cost benefit discussions. Typically, the engineering designers were positive about the potentials of involving ergonomists in design, due to the possibility to improve the quality of projects. At the same time, however, they were unsure about the cost benefits of the ergonomists' contributions in relation to *how* and to *what extent* the ergonomists should be involved. Therefore, they would like the ergonomists to present cost benefit arguments. Many also found that involving ergonomists implied increased complexity of the design projects.

> PM: "I don't think that there is any area where it [the involvement of ergonomists] hasn't worked well. But I sometimes think that we spend too much money on it."
> ED: "All I am saying is that maybe one should look at what is gained on the bottom line for the money spent on ergonomics. Would it have been okay with less? ... It costs extra to say, 'No, we have to move this.' Does it really create better working conditions?"
> PM: "Ergonomists should be much more specific on why they are worth the price. They are a little scared of money."

From the perspective of the ergonomists, the benefits of integrating ergonomics into designs seemed more straightforward. The ergonomists believed that their services could contribute to better workplaces for the end users. However, they were reluctant to go into the financial aspects of integrating ergonomics in design. Several ergonomists acknowledged that the ergonomists in general are not good enough at accounting for the cost benefits of integrating ergonomic services into design projects.

> Ergonomist: "We think that we can contribute with something that can improve the buildings for the people who are going to use them. For years, we have been trying to make our colleagues understand this. … The main reason they haven't is that we [the ergonomists] are not communicating properly. We are not accurate enough when it comes to addressing the value of integrating ergonomics in design. … We are still not good enough at arguing for what we can, how to include it, and the difference it makes. Is it a good investment – and why?"

4.4 The role of the client

The ergonomic ambitions of the client and their willingness to pay for ergonomic services constituted a barrier *and* a facilitator for involving ergonomics in design tasks. Participants reported that clients determined whether or not resources were allocated for ergonomics. For ergonomics to be involved in projects, it was necessary that ergonomics was addressed either in the sales material provided by the client, during the initial dialogues with the client, or once the project had been initiated. The general position among the engineering designers was that it was up to the individual client whether or not to involve an ergonomist in the design projects.

> PM: "It is up to the client whether he wants to include it [ergonomics] or not."

Many participants, both ergonomists and engineering designers, found it problematic that the engineering designers had the main contact with the client. One possible pitfall was that the engineering designer would forget to include ergonomic aspects in the sales process. Another

pitfall was if the engineering designers did not have the competencies to sell the ergonomic services.

> PM: "The overall challenge is to sell the ergonomic services and to remember to include ergonomics in sales."
> PM: "It is important that the person who is in contact with the client can make clear to the client what he gets and what he doesn't get. Right now, the building people [the engineering designers] don't know much about ergonomics, and they are the ones handling sales and the dialogues with the client."

4.5 Coping and forming strategies to overcome resource constraints

The ergonomists' efforts to get resources for engaging in design activities were in practice largely dependent on the individual ergonomist. Strategic or planned efforts turned out to have minor effect, as they were not formally evaluated or followed through. A formal staffing procedure in the engineering consultancy was introduced to ensure cross-disciplinary work. According to the ergonomist involved in the staffing procedure, however, the initiative only had minor effect and did not solve the experienced resource constraints. In the ergonomic department, a growth plan for "integration of ergonomic knowledge in design" was developed and approved by the CEO. Subsequently, however, the ergonomists did not manage to 'sell' the plan to prominent design actors, and the initiatives to implement the plan faded out. Finally, we noted that among the ergonomists, there was not much talk about how to make the ergonomic services in design more effective, for instance by introducing uniform ways of addressing ergonomics in design.

In the following, we account for how the individual ergonomist speculated about and developed strategies for acquiring resources both to enter design and become involved in projects.

4.5.1 Coping and forming strategies to enter design

We found that the majority of the ergonomists developed ideas about how to gain access to design projects. A couple of the ergonomists talked about how to promote their services to the engineering designers.

> Ergonomist: "We shouldn't tell them [the engineering designers] what we can do. We should listen to what their tasks are and *then* describe how we can improve their project – also profit-wise."

Other ideas were related to the challenges of getting paid for ergonomic services. One ergonomist suggested promoting ergonomic sale by focusing on services that the engineering designers were not saying they were providing already – for example, the ergonomist's ability to facilitate processes. Another idea revolved around introducing different 'ergonomic packages', which could be included in sales, for instance, in the form of an idea catalogue with a guiding price list. This was also suggested by engineering designers. Several of the ergonomists also argued that gaining access to the client would enhance the possibilities of being involved in design projects:

> Ergonomist: "It is the client who decides which music should be played."

One often proposed strategy was to team up with the engineering designers at the sales stage. This strategy was used successfully in the seafood case, where a leading manager in the ergonomic department and the PM had teamed up in the sales stage and managed to sell ergonomics as an extra service in the design work – at additional cost to the client. One engineering designer reported however that teaming up in sales was not always successful:

> ED "There are some of our customers who view consultants as a burden on their budget. They have to use us, but it is a necessary evil. And everything that raises the cost will make them put their foot down. … I cooperate a little with ergonomists on sales for a number of clients who I am in charge of. … but it's very hard to get in, because most of them have the attitude that 'ergonomics is something we can take care of ourselves'."

4.5.2 Coping and forming strategies once involved in projects

Once involved in a design project, individual ergonomists developed different strategies for obtaining resources during the course of a project. Most ergonomists sought resources through discussion with projects PMs. Some carefully considered how to engage in resource-related discussions, while others were less structured in their approach. One structured approach was to make internal contracts with the PM, where agreed ergonomic activities were listed along with deadlines and time estimations. The ergonomist who used this strategy recommended it as a means to engage professionally in resource discussions. When asked to carry out additional tasks, he would refer to the internal contract and argue that more hours were needed to complete the additional task.

In the hospital case, we found that the leading ergonomist sought to obtain resources for ergonomic services by aiming directly at the "ergonomic ambitions of the client". He had great success in going around the already established contact between the engineering designers and the client, and managed to create an alliance with an ergonomist working for the client

organization. Together, they formed an OHS policy for the entire design project, which they made sure to get approved at all management levels. This was described as a breakthrough, as it made the project management team take a stand with regard to the project's ergonomic ambitions. On this basis, the ergonomist from the engineering consultancy managed to negotiate an agreement where 0.15% of the total budget was earmarked for involving ergonomists in design activities. This made a huge difference in the project:

> Ergonomist: "We don't have to explain every time and ask for hours. We are paying ourselves. This makes a huge difference. Everybody has opened up and used us."

The approved OHS policy was deliberately communicated broadly, so that everybody in both the client and project organizations knew of the OHS ambitions. As a result, the OHS policy functioned successfully as a safeguard against cutbacks during the course of the design project.

5. Discussion

We found that resource constraints primarily emerged at 'the internal marketplace' inside the engineering consultancy firm, as ergonomists and engineering designers speculated, discussed and reflected upon their experiences regarding how to integrate ergonomic services into the engineering design processes. A main focus in the engineering consultancy was to maximize the revenue of the individual design projects. This focus, in the absence of a separate 'ergonomics budget', constituted a barrier for the integration, as ergonomics was seen 'as another mouth to feed'. We also found that the engineering designers requested cost benefit arguments for ergonomic services, but that the ergonomists were reluctant to go into this discussion. The client's ergonomic ambitions and willingness to pay for ergonomic services were critical for the possibilities for integrating ergonomics in design.

5.1 Sub-optimization of costs

The design tasks were completed in a client-consultant setting, and in the engineering consultancy we identified a strong focus among the engineering designers on minimizing design costs in order to maximize project revenues. According to Béguin (2011) the division between client and consultant can be problematic, especially if the boundaries between the parties are too impervious. Based on the present study, we suggest that with regard to resource allocation and integrating ergonomics in design, the boundaries do appear to be rather problematic. The 'construction' of split responsibility between consultancy and client in the design and operation phases respectively leads to a sub-optimization of resources. In the engineering consultancy,

this manifests itself in the constant focus on minimizing design costs, which overshadows the focus on optimizing operational costs in the client organization.

The sub-optimization of resources in design conflicts with the rationale behind integrating ergonomics in design: The benefit of involving ergonomists in design should be seen in a joint consultancy and client organization perspective, because the benefits can be largely linked to increased system performance in the client organization (Goggings at al., 2008; Neumann and Dul, 2010; Oxenburgh et al., 2004). It has previously been found that intra-organizational boundaries can be problematic when attempting to integrate ergonomics in design, for instance in manufacturing companies (e.g. Neumann et al., 2009). The challenge for ergonomists engaged in design in a client-consultant setting, however, appears to be to promote ergonomics in a setting where the engineering designers are separated both inter-organizationally *and* financially from the potential savings of involving ergonomics in design. Engineering consultancies that wish to support integration can consider including ergonomics in the organizations' strategic goals (Dul and Neumann, 2009; Neumann and Dul, 2010) as well as *implementing* the strategy, for instance by incorporating 'the selling of ergonomic services' as a goal in internal performance measurement systems. We noted that involving ergonomists was regarded more as a project expense rather than an opportunity to increase overall revenue in the consultancy.

5.2 The key role of engineering designers

The engineering designers were in charge of the design processes, which gave them a key role in relation to integrating ergonomics in design. Their doubt regarding the cost benefits of integrating ergonomic services in design seems to have contributed to shaping the identified resource constraints. A link between key stakeholders perceiving ergonomics to have a low value and scarce resources for ergonomic initiatives has previously been established in the literature (Bruseberg, 2008; Helander, 1999; Whysall et al., 2006). Dul et al. (2012) also argue that the integration of ergonomics in design depends on a demand for ergonomics by design actors. We identified that all the engineering designers were positive about the potential of integrating ergonomics in design in the form of increased quality. However, the ergonomists only experienced to a minor degree a 'pull' from the engineering designers. Following the argumentation by Dul et al. (2012), the "positive expectations" for added value from integrating ergonomics in design obviously did not match the engineering designers' concerns regarding increased project complexity and increased design costs. It appears that among the engineering designers, OHS is mostly seen as an OHS issue rather than a performance enhancing activity. This aspect has most recently been addressed by Theberge and Neumann (2013).

In the engineering designers' key role as project managers, they had the main contact with clients. We hypothesize that this creates challenges for ergonomics being integrated into engineering design practice, because many engineering designers do not have the knowledge or competencies to 'sell' ergonomics. One way to promote the ergonomic agenda is to provide ergonomic training for the engineering designers in order to prime them to be able to address the ergonomic agenda in their dialogue with clients.

5.3 Ergonomists lack cost benefit argumentation

The ergonomists were reluctant to go into the cost benefit argumentation and found it hard to argue for the value of ergonomics. One explanation for this finding is that being part of a commercial market was new to the ergonomists, so they needed to learn to how to act in an engineering consultancy's business-driven design setting. Haslegrave and Holmes (1994) argue that design is a commercial discipline where cost benefit argumentation is an incorporated part of the practice. Hence, if ergonomists are not able to meet engineering designers' requests for cost benefit arguments, this contributes to reinforcing resource constraints. As previously noted, difficulties in arguing for the cost benefits of ergonomics have often been described in the HF literature. According to Tompa et al. (2010), the lack of economic evaluations of ergonomic initiatives can partly be ascribed to the ergonomists' lacking ability to conduct these evaluations. Recently, more evaluation models have been developed, and several evaluations showing the cost savings of ergonomic initiatives have been published (de Looze et al., 2010; Oxenburgh et al., 2004; Rose et al., 2013; Tompa et al., 2010; Tompa et al., 2013). Despite the identified difficulties in expressing the cost benefits of ergonomic services, we support previous publications (e.g. Beevis, 2003 and Dul et al., 2012), which argue that ergonomists need to be able to enter into dialogue about the cost benefits of ergonomics in order to be able to demonstrate the value of ergonomic services and thus *sell* ergonomics to main stakeholders. In relation to the identified resource constraints, however, it is a challenge that economic evaluations and cost benefit analyses can be quite time consuming to conduct (Tompa et al., 2010). In a business-driven setting, it might be difficult to obtain resources to conduct such evaluations. An alternative strategy for ergonomists is to rhetorically link the ergonomic initiatives to system performance goals by using 'goal hooking'. The underlying idea here is that it might be easier to implement ergonomic initiatives, if system designers can see that it contributes to fulfilling their own goals (Dul and Neumann, 2009; Whysall et al., 2006). It might also diminish the need for cost benefit arguments, if engineering designers can see that ergonomic services contribute to fulfilling their own goals.

5.4 Competencies to overcome resource constraints

Organizational and strategic initiatives played only a minor role in ergonomists' coping strategies in relation to the identified resource constraints, as these strategies were either not implemented in practice or not able to overcome the identified constraints. Hence, at the operational level in the engineering consultancy, overcoming resource constraints depended heavily on the individual ergonomist's ability to act in the setup of engineering design practice. One of the identified strategies among the ergonomists for working around the resource constraints was to *identify* and *pursue* the ergonomic ambitions of the individual client. Especially the leading ergonomist in the hospital case was exemplary in his ability to strategize and reflect about how to work around the resource constraints he experienced. Drawing on Broberg and Hermund's (2003) concept of the "political reflective navigator", we argue that this ergonomist was able to fulfill this role. He was "skilled in political and reflective processes" (Broberg and Hermund, 2003, p. 324) and succeeded in building alliances that helped him to push the ergonomic agenda. Neumann et al. (2009) distinguish between navigating as an internal or external navigator. In the hospital case, an alliance was formed between an internal and external 'ergonomic navigator'. This alliance proved successful in relation to working around the problematic boundaries of the client-consultant setup and overcoming the constraints related to obtaining resources for ergonomic counseling in projects. A prerequisite for using this strategy, however, is that it is possible to identify an ergonomic navigator in the client organization, and that this navigator has the skills to establish a power base among decision makers.

Finally, we also noted that among the ergonomists, there was not much talk about how to make the provision of ergonomic services in design more effective by for instance introducing uniform ways of addressing ergonomics in design. There was some talk about introducing 'ergonomic packages' to support engineering during sales, but this had not been implemented at the time of the study.

5.5 Implications for practitioners

Based on the present study, we argue that possibilities for integrating ergonomic knowledge into engineering design processes in a business-driven setting largely depend on the ergonomic ambitions of the clients as well as the individual ergonomist's ability to act in relation to design. We hypothesize that engineering consultancies and ergonomists wishing to promote the integration of ergonomic services in design processes can:

- Pursue the ergonomic ambitions of clients by 1) teaming up engineering designers and ergonomists in sales, and 2) identifying and creating alliances with stakeholders in client organizations that can promote an ergonomic agenda inside client organizations.

- Provide ergonomic training for engineering designers in order to enable them to address ergonomic issues in dialogues with clients.
- Provide engineering design training for ergonomists to enhance their understanding of and ability to act in design processes.
- Start a standardization process with an aim of developing 'standardized ergonomic design services' that can be linked to engineering design processes, which may reduce the cost of integrating ergonomics in design. A related recommendation is to create an idea catalogue featuring the 'standardized ergonomic design services', which includes cost benefit estimates. Such a tool should aim to support engineering designers during the sales stage and support ergonomists in dialogue with both internal and external stakeholders.
- Consider including ergonomics in the engineering consultancy's strategic goals and taking initiatives towards implementing the strategy, for instance by including 'selling ergonomic services' as a goal in performance measurement systems.

5.6 Limitations

The study has some limitations. Since the findings in this paper are based on a single case study, it can be argued that they cannot be generalized to a larger population (Thomas, 2011). Furthermore, the overall subject of the conducted interviews was "integration of ergonomics into engineering design", which can be seen as carrying a specific agenda, namely that ergonomics should be involved in design projects. The interviewer was aware of this. As part of the study, it was interesting to learn about different viewpoints as to whether or not ergonomic services should be included in design processes and the challenges this would present. It turned out, however, that all the interviewed engineering designers appeared to be positive about the potential benefits of integrating ergonomics in design processes. This could be because they considered the interviewer (the first author) to be 'an ergonomist'. Such an effect is known as 'social-desirability bias' (Bailey, 1994), which refers to the possibility of respondents answering in a way that makes them look better in the eyes of the interviewer.

In further studies, it could be interesting to test whether the finding and conclusions of this paper apply in other similar but also different settings.

6. Conclusion

In this paper, we set out to explore the shaping of resource constraints when integrating ergonomic knowledge into the engineering design processes in an engineering consultancy. Based on our findings, we hypothesize that the resource constraints were shaped as a consequence of a sub-optimization of costs in design jobs undertaken in a client-consultant setting, in that potential savings in connection with ergonomic initiatives should be evaluated on the basis of the 'life cycle' of the designed workplaces. Some organizational initiatives were established to overcome the resource constraints, but they seemed only to have a minor effect. In practice, the ability to overcome the resource constraints depended largely on the individual ergonomist's ability to act in an engineering design setting. The most successful strategy to overcome the resource constraints proved to be to pursue the ergonomic ambitions of the individual clients, either by teaming up with engineering designers during the sales stage or by creating an alliance with an 'ergonomic navigator' in the client organization.

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Learning opportunities across knowledge domains

Abstract

Purpose – The purpose of this paper is to shed light on the problematics of learning across knowledge boundaries in organizational settings. We specifically explore learning in cross-boundary processes, when a new knowledge domain is introduced into an existing organizational practice with the aim of creating a new and combined practice.

Design/methodology/approach – A case study was carried out as a "natural experiment" in an engineering consultancy, where emerging initiatives to integrate the newly acquired competencies into the existing practice were explored. A theoretical framework informed by different perspectives on learning, boundary and knowledge management was applied on three illustrative vignettes to illuminate learning potentials and shortcomings in the boundary processes.

Findings – In the engineering consultancy, we found that while learning did occur in the consultancy organization, it remained discrete in 'pockets' of learning; mainly at an individual level, at project level or as domain-specific learning. Learning opportunities were intertwined with elements of domain-specific interests, power, managerial support, structural conditions and epistemic differences between knowledge domains.

Research limitations/implications – The finding in this paper is based on a single case study: hence, the findings' generalizability may be limited.

Practical implications – The paper argues that learning across knowledge domains needs various forms of supporting initiatives and constant readiness to alter or counteract when an initiative's shortcomings appear or undesired learning loops arise.

Originality/value – The paper contributes to understanding the complexity of learning across knowledge boundaries in organizational settings.

Keywords Knowledge domain, Knowledge sharing, Boundaries, Learning

Paper type Case study

Introduction

Knowledge and knowledge creation are important factors in a company's ability to survive and compete in today's knowledge-based economy. According to Barney (1995), a company's competitive advantage depends on its internal resources and capabilities *and* the company's ability to exploit and combine these assets. In an attempt to achieve competitive advantage, some companies choose to follow a differentiation strategy. The potentials of working across different practice domains has been broadly recognized in the literature in terms of achieving

strategic advantages, creating learning opportunities and developing innovative solutions (Carlile, 2002, 2004; Kreiner and Lee, 2000; McDermott, 1999; Wenger, 2000). However, studies have also shown that establishing new routines and practices across different knowledge domains can be rather challenging, due for instance to the different 'object worlds' existing between practices and the internal focal points of practices, which can isolate them from the broader context they are a part of (Brown and Duguid, 2001; Bucciarelli, 1994; Kakavelakis, 2010; Kreiner and Lee, 2000). Brown and Duguid (2001) have succeeded in increasing our understanding of 'intercommunial' behavior and 'intercommunial' negotiations, and Kreiner and Lee (2000) have explored how individual actors pursue possibilities for innovation. We argue, however, that more knowledge is needed regarding the challenges of working across knowledge boundaries, and particularly the learning opportunities that emerge when organizations seek to combine competencies of different knowledge domains with the aim of innovatively improving existing organizational practices. The aim of this study is to explore the opportunities and problems connected with learning across the boundary between different knowledge domains in organizational settings. The term 'knowledge domain' refers to knowledge that is specific for a given domain of practice, both in terms of more abstract knowledge and knowledge embedded in the social, organizational and material context of a given practice.

In this paper, we report on a case study of an engineering consultancy that, as part of their differentiation strategy, acquired two different Occupational Health and Safety (OHS) consultancies. The aim was to be able to address the market with new commercial services that combined OHS competencies with the already existing technical competencies in the company, which would hopefully lead to a competitive advantage. Through the case study, we explore the learning opportunities that arose in the meeting between two knowledge domains that had no tradition of working together. Through the use of illustrative vignettes, we focus on initiatives at different levels of the organization and identify learning opportunities and shortcomings at *and* across different organizational levels. Our findings show that learning in the engineering consultancy remained discrete and was mainly identified at the individual level and secondarily at group level. We argue that collective organizational learning was hindered by issues related to power, politics and structural conditions in the company.

The structure of the article is as follows: First, a theoretical framework is introduced, which combines different theoretical perspectives on learning and knowledge management across boundaries. Subsequently, the methods employed in the study and the empirical setting are accounted for. Thereafter, three illustrative vignettes are presented, where initiatives aiming to

bridge the knowledge boundaries are analyzed using the theoretical framework. The paper concludes by addressing initiatives launched at the organization's corporate level, followed by a discussion of the findings which includes implications for practitioners.

Theoretical framework

Learning within and across knowledge domains

'Community of practice' (COP) offers a way of thinking about practice-based learning within and across different practice domains. The notion of COP was developed by Lave and Wenger as a part of their work on situated learning and legitimate peripheral participation (Lave and Wenger, 1991). In this perspective, learning is seen as an integrated part of practice, occuring when tight tension exists between competence and experience (Wenger, 2000). COPs consist of people who are connected through participating in shared practices, and COPs are seen as central elements of larger social learning systems, such as organizations. Inside COPs, learning takes place through alignment processes in which members interact with each other and talk about their experiences. Individual members are said to learn when there is interplay between the socially defined competencies of the community and the personal experience of the individual member (Wenger, 2000), whereas learning of a more collective nature occurs through negotiations of ideas and practices, and it is institutionalized in the development of tools, symbols, stories and practice routines (Macpherson and Clark, 2009). A central issue in COP revolves around identity; a focal point is *becoming a practitioner* rather than leaning about practice (Brown and Duguid, 1991). The "*sense of identity is important because it determines how an individual directs his or her attention*" (Lesser and Stork, 2001, p. 832), and the focus of attention is central to the shaping of learning processes (Lesser and Stork, 2001).

Meetings between COPs contain great learning opportunities, because experience and competences often diverge in boundary meetings between practices; however, the meetings can also generate challenges. Epistemic barriers often exist between practices, and experiencing a boundary might reinforce the boundary rather than bridge it (Brown and Duguid, 2001; Bucciarelli, 1994). According to Wenger (2000), bridges between practices can be established through: people acting as 'brokers' between communities; using boundary objects (artifacts such as things, terms, tools); setting up interactions (visits, discussions, meetings); or cross-disciplinary projects.

Based on studies of engineering design, Bucciarelli (1994) also addresses epistemic differences between knowledge domains and introduces the term 'object worlds'. He argues that different knowledge domains have different principles and approaches in problem solving, and also have

their own way of seeing the design *object* in question. Engineering design is described as a social process of negotiations and tradeoffs, where each knowledge domain has quite different viewpoints on what an optimal 'solution' might be. A central aspect of managing engineering design is thus to contribute to the establishment of a common language, which makes it possible for design actors to address problems on a common ground and reach some degree of consensus. This requires a precise and meaningful labeling of both artifacts and processes: "The label has to be right. Design participants struggle over words. Naming is designing" (Bucciarelli, 1994, p. 174).

Boundary complexity

Carlile (2002, 2004) addresses the complexity of working across knowledge boundaries and introduces different approaches to managing boundary processes. The complexity of a boundary is defined through the *differences* between knowledge domains, the *dependencies* between them and the *novelty* with exists at the boundary. A high degree of novelty at a boundary creates uncertainty regarding both the differences and dependencies between knowledge domains, and the amount of common knowledge for handling specific concerns will be small. This is the case when introducing a new knowledge domain into an existing organizational practice. The complexity of a given boundary will be decisive for whether or not a given approach will be effective in bridging the boundary. Carlile (2004) distinguishes between a pragmatic, a semantic and syntactic approach (see Table 1).

Table 1: Approaches to managing knowledge boundaries (based on Carlile, 2004)

Syntactic approach	**Transfer – creating a shared syntax between practices** An information processing approach where the focus is to store and retrieve knowledge.
Semantic approach	**Translate – creating shared meanings across practices** An interpretive approach focusing on creating a shared meaning between actors. The focus is on identifying sources of differences, making them explicit, and acknowledging dependencies. Potential consequences of differences and dependencies are however not in focus.
Pragmatic approach	**Transformation – negotiating practices and transforming practices** A political approach that acknowledges that when different interests exist among actors, it complicates knowledge sharing and learning across boundaries. The focus is on understanding and *resolving* negative consequences. In dealing with negative consequences actors from different knowledge domains need to *transform* their own practice.

Carlile also argues that the challenge of working across boundaries is not only that knowledge is *located* within the different practices. Knowledge is also *invested* in practices, both in terms of the time and resources needed to acquire and maintain a certain knowledge base (Carlile, 2002, 2004), but also in terms of the desired effects of engaging in practice. For example, OHS consultants' aim is to create good working conditions, while the engineering designers' aim is creating good buildings. Hence, when engaged in practice, knowledge is at stake for the individual actors, and reluctance to alter knowledge and skills will often exist. Elements of power can also become an issue, especially when a high degree of novelty exists at a boundary (Carlile, 2002, 2004).

Managing knowledge and learning across boundaries

In an organizational perspective, managing knowledge processes requires more than launching initiatives, for instance, at project level. People, structures, and processes are interwoven through complex dynamics, and opposing forces may exist in different layers of an organization. Managing this is not an easy task. When attempts are made to create virtuous learning circles, this may lead to unexpected negative consequences that can generate vicious and undesired learning circles (Senge, 1990). Consider for instance the use of reward systems, which on the one hand may encourage employees to strive for certain desired outcomes. On the other hand, a one-sided focus on a certain outcome may also make employees lose sight of other important aspects on an ever-changing market. Hence, managing knowledge learning across boundaries requires efforts directed toward balancing opposing forces in the organization as well as initiatives to couple knowledge initiatives within *and* across organizational levels – e.g. the individual level, group level, and overall collective level (Garud and Kumaraswamy, 2005).

Method

A case study was carried out in an engineering consultancy in Denmark. The study can be characterized as a 'natural experiment' in which we sought to gain insights into learning opportunities across knowledge boundaries in a 'natural setting' (Bailey, 1994). The experimental conditions were out of the researchers' control. Over a period of three years, we studied how actors handled the integration of the newly acquired OHS competencies in the engineering design practice.

Research Design

The case study was conducted as an embedded case study (Yin, 2009), in which the engineering consultancy constituted the overall case unit, and three different design projects were selected as the embedded cases. The embedded case study was chosen, because we wanted to gain

insights into the studied phenomenon at different levels in the organization and across different knowledge boundaries. “Purposive sampling” (Miles and Huberman, 1994) was used to select the cases. The selection criterion was: “Design cases where the OHS knowledge domain to some extent has been involved.” The three embedded case units were: the design of a sterile processing plant; the design of a hospital; and finally, a conceptual design plan for a seafood company.

Data collection

The primary data source was interviews, which were supplemented by observation. A total number of 26 semi-structured interviews were carried out, involving 23 informants (OHS consultants (n=10), engineering designers (ED) (n=11), CEOs (n=2)). Both EDs and OHS consultants were interviewed to ensure a variety of perspectives on the studied phenomenon. The interviews were semi-structured and emergent (Kvale, 1996). During the interviews the participants addressed different aspects of integrating the new knowledge domain into the existing practice, in relation to the individual, group, and corporate levels. The interviews were conducted as face-to-face interviews and varied in length from 30 to 120 minutes. They were audio-recorded and all essential parts were transcribed. There were three exceptions – two where the interviewees did not wish to be audio-recorded, and one where no audio-recorder was available. Informal ethnographic interviews (Spradly, 1979) were also part of the data material, where notes were taken after the ‘conversations’.

The data collection period stretched over three years, from 2009 to 2012. During this period, the first author spent approximately two working days per week at the engineering consultancy – the first two years as a part of an engineering department, and the last year in an OHS department. This allowed insights into different actions, interactions and events. Field notes were taken when anything related to the subject of interest was experienced.

Data analysis and presentation

The interview transcripts and field notes were read several times and carefully examined on the basis of the theoretical framework. Special focus was on identifying learning opportunities as well as shortcomings. The analysis process can be characterized as an emergent process, where the first author moved back and forth between the data and theories in order to understand the case material through the theoretical framework and make sure that our interpretations and claims were supported by the data. Throughout the process the second author had the role of counteracting potentially biased interpretations by questioning the findings and claims and suggesting alternative explanations etc.

The findings are presented through vignettes. The vignettes are included in order to give detailed descriptions of specific attempts to integrate the OHS knowledge domain into the engineering design practice and analyze the episodes. We do not argue that the vignettes reflect the full complexity of the entire data material. Rather, the vignettes are chosen to *illustrate* how the learning opportunities were affected by the complexity *between* the knowledge domains. Three small vignettes are selected from the hospital case. The rationale for selecting vignettes from this case is that it represents a critical case (Flyvbjerg, 2006): This case was often referred to as *the* case in which OHS competencies had successfully been integrated. Findings based on a critical case allow for "generalization of the sort, 'If it is valid for this case, it is valid for all (or many) cases'" (Flyvbjerg, 2006, p. 230).

The case: Integrating of OHS knowledge into engineering design practice

The engineering consultancy provides design services to a number of different business areas such as hospitals, food producers, breweries, dairies, pharmaceutical companies and investors. It can be characterized as a knowledge intensive firm, where the entire revenue is based on consulting. During the years 2006-2007, the consultancy acquired two different OHS consultancies with approximately 105 OHS consultants. At the time, about 600 EDs were employed in the consultancy. The acquisitions were part of the company's differentiation strategy: They wanted a greater variety of competencies with which to access the market; both in terms of stand-alone services and as combined services, which hopefully would lead to a competitive advantage for the engineering consultancy in terms of high quality solutions. In this paper, we focus on the combined services.

At the time of the study, the consultancy was in a phase of transition: three other smaller consultancies were also acquired during this period and a major organizational change had been introduced shortly before the acquisitions. Organizationally, the OHS consultants were placed within their own competence area in the new matrix organization, and physically they were placed in 'OHS department spaces' in the engineering consultancy's offices. For the employees in the OHS consultancies, the transition from being employed in smaller OHS consultancies to being part of a larger company was additionally 'complicated' as the area of OHS consulting in Denmark went through a major change in the same period: Due to a political decision, public funding for OHS services was phased out; as a result, the OHS consultants went from having 90% of their business covered by subscriptions to having to compete on the private market.

In the engineering consultancy, various initiatives were launched at the corporate level to support the development of a combined practice (see Table 2).

Table 2: Main initiative launched to support cross disciplinary work

Initiative	Explanation
New strategy and mission statement	Focus on cross-disciplinary work and sustainability
Matrix organization	Integrate the OHS consultancies into the existing matrix organization
Staffing process	A formal staffing process was introduced with appointed staffing coordinators. The aim was to stem informal staffing processes.
Competence wheel	An illustrative 'competence wheel' was launched to highlight the five main competence areas in the company (Building, Process, OHS, Environment, Business). To the extent possible, all competencies should be brought into action in design projects.
Delivery model	A delivery model was launched on the company's intranet. The purpose was to make uniform processes, create a common frame of reference, and establish a knowledge repository where employees could learn about what other knowledge domains could contribute to different design phases.
11 o'clock news	The company's daily 11 o'clock news update was used actively to promote cross-disciplinary work by reporting on successful cross-disciplinary projects.
Integrated design process	A uniform approach to design called "integrated design" was launched. The language used in this framework corresponded to the CEO's vision, and a few of the engineering designers were already using this approach.
Slogans like "Dare to advise"	The slogan "dare to advise" was often articulated. The aim was: "Make the client demand what *we* believe is the right solution."
Linking marketing managers	The OHS marketing manager was physically placed next to the engineering marketing managers with an aim of promoting the sale of combined services.

Activities aiming at a combined service also started to emerge at other levels of the organization, mainly upon the initiative of individual actors who saw the potentials of combined service.

In 2011, a new CEO entered the company, and the rhetoric around integration of ergonomic knowledge in design was toned down. With the aim of creating greater transparency

regarding the profit performance in the company, a new division-based organizational structure was introduced. The OHS consultants were now placed in one division and the EDs in other divisions, e.g. buildings and process.

The knowledge domains

Following is a short description of the two main knowledge domains in the company.

OHS consultants

The OHS consultants have different professional backgrounds, e.g. physiotherapists, psychologists, and technicians. Although many smaller COPs existed within the group of OHS consultants, the group as a whole can be characterized as having fairly similar object worlds, with shared norms and repertoires such as languages, artifacts, tools and stories. The knowledge domain is highly regulative, and traditionally OHS consultants are called upon to provide consulting in varies types of organizational settings when OHS problems arise. Engaging in engineering design was new to most of the OHS consultants. In their approach to design, their main focus was on creating good working conditions for end users, a focus that seemed deeply rooted in their identity. When engaged in design, they analyzed and evaluated impact on humans in terms of both qualitative and quantitative assessments, and generated requirements or recommendations for other design actors to take into consideration when designing.

Engineering designers

The EDs include engineers with different areas of expertise. The overall group of EDs consists of many smaller COPs, each with their specific focus, e.g. plumbing, electricity etc. In contrast to the OHS consultants, they were all used to working in a project-based organization and being engaged in engineering design. Common for EDs in general is a main focus on the technical parts of a system. Problem solving is a central aspect of EDs' identity, and they are driven by the aim to make good solutions from the point of view of their particular object world. The EDs rely on being able to verify and test solutions through quantification and measurements. In their approach to design, they go for the optimal solution within the existing financial, organizational or technical constraints (Jørgensen, 2009). Their aim in design can be described as a combination of delivering good 'products' for the clients *and* balancing the design budget. When characterizing the EDs and their approach to design, one CEO referred to an unofficial slogan in the company: "We are engineers – it can't be that difficult!"

Vignettes of learning processes across knowledge boundaries

The following three vignettes are from the hospital case. Through these vignettes, we address how OHS consultants made attempts to bridge the boundary between OHS and ED at project level, and we identify shortcomings as well as learning opportunities in the different initiatives.

The design of the hospital was completed in a large design consortium, which in addition to the engineering consultancy consisted of two architectural firms, two other engineering consultancies, and three sub-consultants. Approximately 20 % of the design actors in the consortium were employed in the engineering consultancy: 1-3 OHS consultants were engaged in integrating OHS into the design process, and 20-25 EDs were engaged in various engineering disciplines. Due to the setup of the design project, the launched OHS initiatives were aimed at both the EDs and the architects.

Vignette: Database for knowledge transfer in hospital case

When the project was initiated two OHS consultants from the engineering consultancy were assigned the task of integrating OHS considerations into the project. They soon realized that to reach 100 to 130 EDs and architects to work on different aspects of the design would involve a huge variety of documents. So they decided to develop an OHS database featuring OHS considerations for standard rooms in the hospital. The data base was intended to be used as a tool to enable EDs and architects to read about OHS regulations and recommendations for standard rooms, e.g. medical rooms, which they then could take into account when designing. The database was intended to reduce face-to-face counseling, not replace it.

The two OHS consultants spent a lot of time designing the database and did outreaching work to identify main OHS impacts experienced at existing hospitals. These findings were included in the database. In the beginning, the OHS consultants were rather excited about the database, and the preliminary feedback on the idea from EDs and architects was also positive. Later in the process, however, the database was not well received by the EDs and the architects. One of the OHS consultants pointed to a number of reasons for the failure, but still believed in the potentials of the database:

- For the EDs and architects it was yet another tool to access for information.
- The database was not integrated into the design database that the EDs and architects were already using. It was a separate database that they had trouble locating.
- Too few resources to develop the tool: The EDs found the database incomplete. In its existing form, the EDs and architects had to become acquainted with the OHS legislation and OHS guidelines themselves. The OHS consultant would have liked *interpretation*s of legislation and guidelines to be added but did not have resources to include this.

- For the EDs, the consequences of accessing the database and learning about OHS considerations were too wide-ranging in that some of the preliminary designs of the hospital would have to be redesigned.

The choice of using a database in trying to bridge the boundary can be characterized as a syntactic approach. The OHS consultant's reflections on the shortcomings of the database reveal several problems of using this approach. First of all, there is an element of information overload, as the database became "yet another tool" for the EDs to access. Moreover, in choosing to use an "information transfer" strategy, the OHS consultants underestimated the complexity of the boundary: The *consequences* of accessing the database and taking the OHS requirements into account were too wide-ranging for the EDs, as this would mean great changes would have to be made in the existing design proposals. This revealed that hard-won knowledge was at stake for the EDs. The vignette also suggests that knowledge was at stake for the OHS consultants as well: Even though they pointed to a number of shortcomings in the database, they still believed in its potential, possibly due to the many hours invested in developing it. The OHS consultant's reflections also indicate elements of learning, but they did not have the character of *transforming* existing practice, where negative consequences are taken into account. Rather the changes the OHS consultant talked about were of semantic character: including *interpretations* in the database. Shortly afterwards, the two OHS consultants were replaced (due to other reasons) by another OHS consultant from the engineering consultancy. The 'new' OHS consultant found the material in the database very useful to him, but he addressed the reason why the database never became a successful boundary object:

> … the idea was that it [the database] could be given to the architects and engineers. Then they could easily identify the relevant impacts for the rooms they were about to design, and easily locate legislative material. Since then, however, it has become obvious that not even this is accessable enough for the architects and the engineering designers…. You can't just hand them some guidelines and say read this – then you will know everything there is to know about OHS. It has to be translated to the specific practice, and the prioritizations that have to be made should be made by OHS consultants; otherwise, it has too little effect. All in all, the ideas [behind the database] were okay, we just underestimated what it takes to reach an actual integration of OHS.

In the handover of the database, the seeds of more *transformational* learning can be identified: The new OHS consultant concluded that a different approach to practice was needed.

Vignette: Requirement list vs. Recommendation list

In this vignette, we present one of the initiatives the new OHS consultant and his new OHS team launched to bridge the boundary. They introduced a prioritized OHS requirement list with approximately 50 requirements, which the ED had to comply with. The list contained both quantitative and qualitative requirements within seven OHS areas, e.g. light, noise & acoustics and psychosocial aspects. Two examples of requirements are included here:

> Good acoustics should be ensured for offices and meeting rooms in the form of a maximum reverberation at 0.8 seconds.
>
> Artificial lighting should accommodate the work processes that take place in the individual rooms (light intensity, representation of colors, reaction time etc.).

The introduction of the requirement list was met by a request to provide financial assessments for all requirements, and the ED and the architect found the list to be restricting. The OHS team soon realized that it would be to wide-ranging to calculate all the financial impacts of the requirements. To solve the conflicting issues, they turned to the engineering design manager for support. He helped them communicate the intentions behind the requirement list, and with his cooperation the name of the list was changed from 'requirement list' to 'recommendation list'. The new label was accompanied by an agreement that if EDs and architects were not able to meet the OHS recommendations, they should come to the OHS consultants and they would jointly arrive at acceptable solutions. Based on this experience, one of the OHS consultants concluded:

> Anchor it in the management system – it needs some weight behind it.

In this vignette, *political maneuvering* to gain *managerial support* became two key components in bridging the boundary. The engineering design manager assisted in finding the right label for the OHS specification list, and the *labeling* helped to connect the OHS consultants and the ED. By substituting the word requirement with recommendation, the OHS consultants were no longer required to provide financial assessments, and a negotiating process between the knowledge domains was introduced.

Vignette: Learning through cross-disciplinary projects.

The 'new' group of OHS consultants were also engaged in other activities aiming to integrate OHS knowledge into design – for instance participating in user meetings. The following small stories are included to illustrate how both an ED and an OHS consultant experienced working together in design:

> The ED had never worked on a project with an OHS consultant before. He described that "all in all" the involvement of the OHS consultants had been positive, as it had created a better hospital for the end users. He found that the mere presence of the OHS consultants at meetings etc. had created an extra awareness about OHS throughout the project. He described the experience of working together with OHS consultants:
> "In the beginning it was a necessary evil. Can't we just do like we normally do? They ask 'sharp' questions and disrupt the process. We are used to fairly streamlined processes, and then they come in and create something and pull us out into another perspective. 'But I was just concentrating on nuts and screws, why can't I just do that?'"

> For the OHS consultant, the experience of being engaged in engineering design was also new:
> "This is the most challenging and professional development work I have ever tried". He elaborated:
> "OHS consultants have a tendency to set the bar high… It has to be the best of the best, and it can't be any other way. But it can. You just have to find the areas where it is okay and where it is not. You know, there are also engineers and architects and they also have an opinion and some priorities on what is technically possible and what the architects think look best. There are a lot of aspects. It's no good just to sit and say 'that's the way it should be and it can't be any different.' Then you won't achieve a good working relationship. You should be prepared to compromise. You just need to know where the limit is: here it is okay to lower the ambitions and here you can't under any circumstances lower the bar, because it can cause problems and the OHS authorities won't accept it… I have been professionally challenged, and it has been very exciting."

In the process of working together in the specific design project, it seems that both EDs and OHS consultants learned from working together, and they acknowledge the different interests and inter-dependency between them. We found that it was mainly the OHS consultants who actually *transformed* their practice and way of doing OHS counseling in the effort to have an impact on the design of the hospital. In this we see an element of power; the EDs were in charge of the design process and engaged in their regular practice, and interference by the OHS consultants was somewhat inconvenient, while the OHS consultants strived to have an impact through various initiatives.

In relation to developing a new and combined practice in the engineering consultancy, we found that the OHS team manager had engaged in several activities to share his experiences with colleagues in the OHS departments: he held presentations and contributed how-to guidelines, for example. Similar initiatives were not identified among the EDs and their colleagues in the engineering consultancy.

Overall case: Knowledge management and learning in a transition process

In this section we address initiatives launched at different organizational levels in the engineering consultancy and address their ability to stimulate learning processes.

Collective level

The CEO, who was in charge at the time of the acquisitions, strongly believed in learning by doing and that experiences in working together would promote the development of a new and combined practice. We found that the initiatives she and the board of directors launched within the first years after the acquisitions mainly aimed at the collective level of the organization, with focus on a) creating a change in the mindset in the organization, and b) institutionalizing routines (see Table 3).

Table 3: The objective of the main initiatives

Objective of the initiatives	Main initiatives
Creating a change in the mindset	New strategy and mission formulation
	The competence wheel
	The daily 11 o'clock news: "story telling"
	'Dare to advise' slogan
Institutionalizing routines	The staffing process
	The delivery model
	Integrated design process
Knowledge repository	The delivery model
Brokering	Linking marketing managers
Structure	Matrix organization
	Division-based organization

We found that while seeds of a new practice were found in a number of settings, and that learning did occur, this happened in discrete 'pockets', as reflected in the presented vignettes, and virtuous circles did not emerge and spread into the combined practice that was hoped for. The steps taken to institutionalize routines were not broadly accepted, and forces in the company strived at maintaining the existing practice in undesired vicious circles. As one of the staffing coordinators said: "There are a lot of anarchists in this company."

Focusing more specifically on the individual initiatives, we find that the 'integrated design process' never was implemented in practice, and the new formalized staffing process was not accepted as mandatory. It also turned out that the real staffing processes occurred at an earlier stage, when contract agreements were made with clients, and at this stage, the EDs and

sales persons did not have a tradition for selling OHS as a part of the design tasks. Employees also pointed out that the delivery model was not used much. An OHS consultant commented:

> My guess is that it is used very little. It is rather non-obligational… It is justified in the sense that we in OHS have to become specific about what we can contribute in the different project phases… But justified in the sense that the project managers now know when to call on us – I don't believe that. The things that are written about OHS in design are partly so longhaired that *I* can hardly understand even the headings… And that makes me think – How might it be for the project managers from the building division who are supposed to use it?

The delivery model is an example of an information transfer strategy that failed as a coordination tool. One of the shortages in the tool was that the domain-specific contributions were not *translated* so they could be understood by other knowledge domains. Moreover, the model also contained innumerable layers and documents.

An element of 'brokering' was deliberately used at 'marketing manager level' as a means of coupling knowledge domains. Besides this initiative, however, brokering was not used as a strategic tool to build bridges across levels in the organization, nor could we identify any corporate setup for project evaluation to ensure that learning loops spread from the project level to the collective level.

After the introduction of the division-based organization, several actors found that this structure did not encourage cross-disciplinary activities: The main division goal was now to generate profit within each division. A shift in the strategic focus of the company was identified. The overall differentiation strategy was replaced by strategies formed locally in each division. The brokering initiative at management level was dropped, and the initiatives meant to create a mind change in the company also faded out.

Group level

We found that an "OHS-in-design" group was established across the OHS departments. This step towards coupling individual learning experiences from projects to the group level was taken on the basis of employee initiatives. However, while this initiative contributed to learning among the members of the group, the learning experiences remained domain specific, because only a few steps were taken to establish connections between the group and EDs.

Individual level

Over the years, the development towards a new and combined practice was mainly based on steps taken by individual actors or a couple of actors in different parts of the organization, acting on opportunities in the market to combine services on projects. We found that more and

more engineering designers also turned to the OHS consultants to ask for advice regarding specific problematic aspects of their projects. The corporate initiatives towards creating a change in the mind set in the organization may have contributed to this development. In a few cases, we also identified actors starting to create brooking pairs across the boundary of the engineering domain and the OHS domain. In this way, learning loops did emerge based on sporadic bottom-up initiatives, although no combined practice was developed fully.

Discussion and Implications

Through the illustrative vignettes and the analysis of the corporate level, we found that there remained only discrete 'pockets' of learning. Learning elements were identified at the individual level, at project level or as domain-specific learning. Individual learning and learning at project level occurred either when reflecting on shortcomings of integrating attempts or through engaging 'successfully' in practice. Domain-specific learning was identified within the OHS knowledge domain, when OHS consultants shared experiences. Learning of a more collective nature (Macpherson and Clark, 2009), where ideas and practices are negotiated across boundaries and institutionalized in tools, symbols, stories and routines, was not identified at the corporate level, although top-down attempts to institutionalize routines were introduced. The learning processes were intertwined through elements of power, politics, structural conditions, managerial support and epistemic differences in knowledge domains. In the following, we discuss some of the main factors that affected the learning processes in the case studied.

The knowledge domains

Besides epistemic differences between the two overall knowledge domains, we also identified an uneven balance of power between the knowledge domains, which became evident in steps which were taken towards the development of a new practice: The EDs were engaged in their regular practice, which the OHS consultants strived to become a part of. According to Carlile (2004), this problem can be related to the 'path-dependent nature of knowledge', which can be especially problematic when a high degree of novelty exists at the boundary. Among the EDs, there was some resistance to change, which according to Carlile (2004) cannot only be subscribed to the costs of learning but also to the cost of altering the current knowledge path. In order to have an impact on a practice that is 'resistant to change', transformational learning was needed, especially among the OHS consultants.

We also identified resistance related to the introduction of OHS requirements. According to Bucciarelli (1994) resistance will often occur when introducing regulative constraints in engineering design practice, because the regulations will be looked upon as "not invented here" and enclosed with suspicion and possibly also disrespect. As identified in the vignette on

requirements vs. recommendations, Bucciarelli (1994) also argues that reaching a state where regulative inputs, like requirements, can be accepted as legitimate requires a process of negotiation in which multiple interests can be aligned. Due to the social nature of design, this is preferably done through face-to-face interactions.

Objects

Both at project level and the corporate level, boundary objects played an important role in attempts to integrate the new knowledge domain into existing practice. The attempts revealed, however, a number of shortcomings and prerequisites for the use of boundary objects. Both the database used in the hospital case and the delivery model introduced at the corporate level in the engineering consultancy were designed on the basis of an information transfer approach. In accordance with Carlile (2002, 2004), a shortcoming of employing this approach is that the information embedded in the objects were not *translated* to be understood across the boundaries. The location of the web-based knowledge repositories, and the amount of information embedded in the repositories, mattered, and issues like information overload (Brown and Duguid, 2002) were identified. Garud and Kumaraswamy, (2005) address this problem. They argue: "*It has become all too easy to accumulate knowledge in digitized form. However, after a point, search and recontextualization costs outweigh the potential benefits from reusing the knowledge*" (Garud and Kumaraswamy, 2005 p. 13). Based on the identified shortcomings, we argue that great attention should be given to the *design* of boundary objects, including the labeling of objects (Bucciarelli, 1994), and it is necessary to always be prepared to introduce additional initiatives to alter a boundary object if flaws become apparent. Furthermore, this study suggests that while a knowledge transfer approach may be appropriate within knowledge domains, additional initiatives are needed when crossing knowledge domains, such as face-to-face interactions where conflicting criteria can be aligned.

Managing knowledge and learning processes across knowledge boundaries

Even though initial steps were taken toward simulating a new practice, a combined practice was never fully developed. There are multiple explanations for this. We found indications that vicious learning circles in the company strove to maintain the current practice in the consultancy. According to Garud and Kumaraswamy (2005) and Senge (1990), vicious learning circles evidently exist and emerge parallel with the emergence of virtuous learning circles, due to multiple interests among actors in an organization. A central task in knowledge management is thus to steer out of and around the vicious circles and seek to balance the fate of the overall system. Attempts to institutionalize routines were not implemented in practice; possibly due to a lack of supporting initiatives such as brokering or feedback loops, which could have

stimulated the emergence of a new practice at and across different levels of the organization. The introduction of such initiatives or any other initiatives might also generate unexpected or undesired consequences; therefore, the act of balancing requires a constant readiness to alter initiatives or introduce additional actions. We argue that managing knowledge processes across different knowledge domains requires attention to the complexity of the boundaries to be crossed and an effort to identify the underlying drives of undesired circles (Garud and Kumaraswamy, 2005). This may require that managerial efforts are distributed among actors from within the different knowledge domains in order to avoid "domain thinking" (Garud and Kumaraswamy, 2005). Finally, we also found a shift in the strategic focus in the company, which in combination with a division-based structure hindered the development of a new practice. This stresses the importance of having both managerial support, a strategic focus to guide the development of the new practice, *and* an organizational structure that supports the desired work processes.

Implications for practitioners

We argue that learning across knowledge domains needs supporting initiatives of various forms, and a readiness to change, alter or counteract undesired learning loops as they arise. More specific initiatives include:

- Guide the cross boundary processes with a corresponding strategic focus
- Establish a group of knowledge management coordinators who can monitor initiatives. To facilitate cross boundary processes, the group should include actors from different knowledge domains.
- Introduce elements of brokering across different levels of the organization.
- Introduce multiple feedback loops to capture learning experiences, and couple them to other organizational levels, possibly in the form of project audits or evaluation meetings
- Create joint groups for knowledge sharing *across* knowledge domains where prior experiences can form the basis of discussions and negotiations aimed at a combined practice.
- Support the use of boundary objects, such as knowledge repositories, through face-to-face interaction in order to ensure that tradeoffs are negotiated between actors from different knowledge domains. Feedback loops should also be introduced to ensure that an object actually contributes to bridging boundaries rather than reinforcing them.

Limitations

The aim of this study was to gain an in-depth understanding of learning processes across knowledge boundaries. This made the choice of a single embedded case study appropriate. One of the limitations of single case studies, however, is that the generalizability of such studies may be limited (Thomas, 2011). The findings of this study are also limited by the choice of theoretical perspectives. When carrying out a deductive analysis, the findings are guided by the theoretical perspectives; hence, the choice of other theoretical perspectives might have guided us to different findings.

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