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METHOD DEVELOPMENT FOR THE DESIGN OF SAFETY-CRITICAL SYSTEMS

The space between design research and professional design practice

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ABSTRACT

A common field in academic research is the development and refinement of design methods with the aim of supporting professional design practice. As a result, design practitioners have a wide range of methods and tools at their disposal. However, some studies have shown that the design methods developed through research are not always adopted or used by professional designers. This lack of recognition has been seen as a problem for design researchers. At the same time, practitioners express that researchers do not address the problems of real-world practice and that most methods developed through research are irrelevant or inapplicable because of their failure to consider real-world constraints.

This industrial PhD thesis explores this problem from an insider's perspective at Halogen, a Norwegian design company. Focusing on interaction and systems design, Halogen specializes in safety-critical systems, a field in which poor design might result in the loss of human lives or damage to the environment and the economy. Here, design practitioners interact with the industry, professional users and legislative authorities, often represented by the scientific community of human factors. However, little or no research can be found on how designers use design methods in this particular context.

This problem will be addressed by approaching research as a design practice using the interaction design research triangle. A first-person perspective will be used; I will observe and participate with designers in their everyday professional practice. This approach is guided by the overarching aim to *investigate, in-situ, how design methods for safety-critical systems can be improved.* Central to this approach is the use of the philosophy of pragmatism to understand and explain design methods in a real-world context. The study produced three journal articles that contrast and builds on existing literature on design methods and practice. A proprietary method collection was additionally developed for Halogen to support and assess the translation of analysis to the design of safety-critical systems.

The contribution of this thesis falls into two categories: (1) It offers a theoretical framework for explaining how professional designers use design methods in an unfamiliar, high-risk domain. The theoretical framework could enable further development and evaluation of design methods in the context of real-world design. (2) It offers a mutual framework to help improve the relationship between design researchers and practitioners. Based on pragmatism and a modified interaction design research triangle, the proposed framework overarches the work in this thesis. Combined, the two contributions form new opportunities for research and practice to understand and improve methods for the design of safety-critical systems.

ACKNOWLEDGEMENTS

Firstly, I am grateful for the opportunity that Halogen in Oslo for supporting and funding this industrial PhD research. The commitment and encouragement that the management in Halogen has provided for me, stands as a clear example for how important design is for safety-critical systems. I would especially thank my mentor Stein Helgar for your dedication, determination and support through these three years. Lillian Olsen, CEO, for your strong will and standing up in believing in the long-term effect of this research. Without you two, the research and myself included could have ended up in another place entirely. I am grateful for the support and help from my colleagues in Halogen. In particular the operators and design team that developed the combat information central for the 212CD submarine. You know who you are, and I am proud to have worked with you.

I would like to thank The Norwegian Defence Research Establishment and Kongsberg Defence and Aerospace for supporting this research and allowing certain elements from this research to be published. Important work has been done, so I am grateful that we can shed some light on some of the processes that we have accomplished.

I would also like to thank my research colleagues at the Oslo School of Architecture and Design. Discussions regarding everything from research to food have been a valuable and enjoyable experience. Sigrun Lurås for your keen eye and bright mind. You made me critically dig deep into the nuances of design. I would especially like to thank my supervisor and co-author Kjetil Nordby for motivating and guiding me through these three years. You understood my particular research context before I did and pointed me in the right direction. Your ability to see, understand and communicate what is significant was truly inspirational to experience. Without your bullshit detector and ability to focus on what is important, this thesis would have been difficult to finish.

To my parents for your kind support and interesting discussions. Most of all, I am grateful for the loving support and patience of my wife, Monika, and two children Martine and Emilie. Our trips in the mountains and daily activities has kept me grounded and focused on what is actually important in life. Thank you.

PREFACE

The thesis is submitted for the degree Doctor of Philosophy at the Oslo School of Architecture and Design (AHO) in Norway. As an industrial PhD, this thesis was written as a cooperation between the Department of Design at AHO and Halogen AS from 2015 to 2018. The industrial PhD scheme was developed by the Research Council of Norway to encourage the development of long-term competence and to encourage industries to enhance the interaction between academia and industry (The Research Council of Norway, 2010). Halogen and the Research Council of Norway were the main financial contributors to this thesis. ABB helped finance the first years through a partnership with Halogen.

PART 1

1 INTRODUCTION

How design practitioners actually work in the everyday context of real-world design has been a significant area of focus in the interaction design research community (Stolterman, 2008). As understanding of design practice has grown, an undercurrent of questions about research methods and standards in design practice has grown with it (Gaver, 2012).

Central to this debate is the development of design methods that support professional interaction design practitioners. As first addressed by Rogers (2005) and then later by Stolterman (2008), academics have sought to understand why proposed theories and frameworks have not fulfilled their goal of influencing professional design practice. Therefore, the relevance and real-world applicability of design methods has been a central topic of interest over the last decade (Goodman, Stolterman, & Wakkary, 2011; Gray, 2016; Stolterman & Pierce, 2012). However, these studies mostly draw on an academic concept of design practice, not on in-situ research on how practitioners actually work (Gray, Stolterman, & Siegel, 2014). This, in turn, has led to misunderstandings between design practice and design research. Academics may think that design practitioners are relatively unaware of or uninterested in scholarly theories and methods (Rogers, 2005). On the other hand, design practitioners argue that research does not address their everyday problems and, therefore, fails to offer relevant methods and tools to meet their needs (Stolterman & Pierce, 2012).

In this study, the term 'design methods' will be used to refer to a collection of designerly tools – frameworks, instructions, tools, techniques, and approaches – that support design activities (Stolterman, 2008; Stolterman & Pierce, 2012). To avoid confusion of methods developed through practice and those developed through research, I have coined the term 'practice-generated method.' Practice-generated methods are design methods that have emerged out of and been developed in professional design practices, without direct influence from academia or research. Here, 'practice' refers to professional design activities that create commercial products (Goodman et al. 2011). In contrast, 'research-developed design methods' refers to design methods that have been developed in academic or through formal research and are intended to support design practice.

This thesis investigates the use and development of design methods in an authentic design setting. As an industry PhD, research data is gathered through a first-person perspective within a design company, while being employed as a designer. The study seeks to support researchers and practitioners engaged in understanding and developing design methods for everyday practice, especially in the context of safety-critical-systems. Thus, the focus is on practical methods for design practitioners aiming to create better and safer designs.

1.1 Design practitioners in an unfamiliar domain

As a design practitioner, I have personally experienced the disconnect between research communities and professional design practice. This has become evident in my work designing safety-critical systems, where I have been practising interaction and industrial design for the last ten years. Knight (2002) defines safety-critical systems as systems whose failure could result in the loss of life, significant property damage, or damage to the environment. There are many well-known examples, including medical devices, aircraft flight

control, and maritime and nuclear systems. These systems are also referred to as high-risk environments. In safety-critical design systems, users – often referred to as operators – are professionals who are tasked with specific tasks and workflows, often in complex, demanding work environments. Unlike consumer products, safety-critical systems require the selection and training of dedicated operators. In this particular domain, the scientific discipline of Human Factors (HF) is regarded to be the main authority (Lurås, Lützhöft, & Sevaldson, 2015). The field of HF has been studied for over 60 years, and this research community is dedicated to understanding the capabilities and limitations of humans and to applying this information to the design of appropriate equipment, work environments, procedures, and policies (Rothblum, 2000). As a scientific discipline, HF has roots in psychology, engineering, ergonomics, and cybernetics. This has enabled HF researchers to contribute with an extensive collection of established methods and frameworks.

Until recently, the domain of safety-critical systems was considered outside the field of design. However, there has been an increase in the number of design practitioners working in new, complex, unfamiliar fields, such as offshore and safety-critical systems (Lurås et al., 2015). This transition has created challenges to understanding and defining a designer's role in this particular area. This transition also increases the need for designers to better understand knowledge that, traditionally, belongs to the field of HF. This has become evident in the lack of domain-specific vocabulary and authority in advocating new designs. As Lurås et al. stated, 'To say "I just feel this is right" does not hold in these industries' (Lurås et al., 2015, p. 146).

Correspondingly, HF seems to face similar challenges regarding methods in practice. For example, although HF methods are scientifically developed and theoretically grounded, they have been critiqued for their lack of applicability to conceptualise appropriate designs (Lintern, 2013). A recent study further identified accessibility, usability, and contextual constraints as significant barriers that affect the practical application of theoretical methods. For a theory to be applied in real-life practice, several factors must be considered, including the possibility of a user's failure to focus, the theory's applicability to real, complex environments, the amount of usable data, the time needed and the cost, and the practical outcomes (Shorrock & Williams, 2016).

I would suggest that, for interaction design practitioners without any obvious support in reliable and relevant methods, this disconnect presents a worrying concern for the domain of safety-critical systems. The potential consequences of poor design are severe and can have critical ramifications. This was illustrated by the Deepwater Horizon accident in 2010. A contributing factor to the accident was the design of the operating systems, which limited the capability of the operators to respond in a stressed environment (Bly, 2011). The accident caused the death of 11 workers and released massive amounts of oil into the Gulf of Mexico. The total cost of the damage to the environment, the US Gulf Coast economy, and BP were estimated at $36,9 billion (Smith, Smith, & Ashcroft, 2011). Thus, it is reasonable to suggest that designing a safety-critical system is an important responsibility that affects not only the interaction design community, but also society at large.

Figure 1. The Deepwater Accident in 2010 and the consequence of poor design. Photo credit: US Coast Guard.

Other researchers have addressed the transition of designers into the unfamiliar domain of safety-critical systems (Lurås et al., 2015; Lurås & Nordby, 2014, 2015). The development of practice-relevant design methods has also been examined (Beyer & Holtzblatt, 1997; Gray, 2016; IDEO.org, 2015; Kumar, 2012). However, I have found no previous research examining method development with the goal of supporting real-world interaction design practice in safety-critical systems.

1.2 Research aims and questions

Combined, the abovementioned issues and topics represent a problematic gap for design practitioners transitioning into the design of safety-critical systems. This research gap can be divided into three main areas, which overlap in some ways:

- The lack of formalised design methods that are relevant for design practitioners and applicable to the design of safety-critical systems
- The lack of up-to-date, in-situ knowledge of how design practitioners use design methods in the context of safety-critical systems
- The disconnect in the relationship between practitioners and researchers concerning the development of practice-relevant design methods

In addressing the problems in this thesis, I aim to *investigate, in-situ, how design methods can be improved in the context of safety-critical systems.* Here, in-situ refers to the site

where the actual creation takes place. As an industrial PhD fellow (The Research Council of Norway, 2010), I will conduct this research in-situ at the company where I work, the Norwegian design company Halogen.

To pursue this aim, I will examine three questions that move from the present to the future:

1. How can professional designers' use of design methods be explained?
2. How can research-developed methods be introduced to design practice?
3. How can practice-based design methods be systematically evaluated?

In addition to answering these three questions, I aim to develop design methods to support design practitioners in Halogen. To answer the questions and develop design methods, I will focus on the *design practice* part of the interaction design research triangle and will use pragmatism as a primary approach.

1.3 The interaction design research triangle

Seeking fitting approaches to interaction design research, Fallman (2008) developed the interaction design research triangle, which combines design practice, design studies, and design exploration into one model. Also known as the Triangle, the model has influenced methodological innovations in previous practice-based design doctoral theses (Yee, 2010). In its most basic form, the model is a two-dimensional triangle that illustrates three extremes: *design practice*, *design studies*, and *design exploration*. These extremes are also called 'activity areas' which can be used to plot the position of research activities. Pullin (2014) argues that the activity areas can be used to generate both generic and specific knowledge.

This thesis is positioned in *design practice* to accommodate its focus on real-world research at Halogen. In *design practice,* the steps employed in a study are similar to those used by real-world design practitioners. As part of a small design team, I was involved in designing a next-generation submarine operations room for the Norwegian Defence Research Establishment (FFI). The project was part of the project supporting the Norwegian government in the procurement of new submarines for the Royal Norwegian Navy (FFI, 2017) (Figure 2).

Figure 2. An Ula-class submarine of the Royal Norwegian Navy. Photo credit: Torgeir Haugaard / Norwegian Armed Forces.

This particular real-world field setting gave the study access to tacit competence and in-depth knowledge during the design process. It further allowed the study to develop, test, and implement methods in a restricted field setting. Due to security concerns, electronic tools such as laptops, digital cameras, and smartphones were prohibited. Here, the Triangle allowed for an explorative and pragmatic approach to accommodate the available field setting. This enabled me to act as a bricoleur to qualitatively explore and employ research methods. Also known as a 'jack of all trades,' a bricoleur invents or pieces together multiple methods in the pursuit of an in-depth understanding of a topic (Denzin & Lincoln, 2011). Nelson (1991) explains that, if necessary, a bricoleur will invent new tools for a particular situation. This approach resulted in a range of analogue methods for inquiry and visual interpretive analysis. To further place the findings in the perspective of design practice, I also needed to establish an appropriate theoretical framework for explaining the findings. I have used pragmatism to do this.

1.4 Pragmatism

Peter Dalsgaard (2014) recently connected pragmatism with design thinking by arguing that a pragmatic approach can prompt a systematic understanding of a design situation. Dalsgaard (2014) further points out that Schön (1983) and Buchanan (1992) explicitly draw on pragmatism to understand and transform a design situation in practice. Researcher and design practitioner Kumar states: 'Pragmatism governs thinking about the practicality of making ideas real and devising the reliable tactics to make that happen' (Kumar, 2012, p. 286). This means that actions, situations, consequences, and knowledge do not copy reality

but are means of coping with a changing world (James, 1997). Or, as Creswell (2013) states, truth is what works in real time to produce the desired result.

I draw on the 'primacy of practice' principle to better understand methods in the context of professional design practice. First conceived by Peirce as the maxim of pragmatism, this principle is based on the assumptions that all human activity occurs in a specific situation and that neither the subject or phenomena can be understood outside of that situation (Bacon, 2013). This means that human actions and thoughts – as well as objects and events – must always be understood in the larger context of a situation. This suggests that practice takes precedence over doctrines (Dalsgaard, 2014). In the current study, the primacy of practice principle was central to understanding how professional designers use methods and how design methods can be developed for real-world practice.

1.5 Journal articles

The thesis is based on three journal articles that, together, comprise a comprehensive in-situ study of design methods in professional design practice. Combined, the articles provide three different angles into using, understanding and developing relevant design methods for safety-critical systems. All three articles are summarised and their main findings described in Chapter 5 of this thesis. Following is a brief description of the articles.

1.5.1 Interview guide mapping: Qualitative inquiry in professional design practice

The first article addresses the Interview Guided Mapping (IGM) method (Schønheyder, forthcoming). The method was developed by design practitioners in Halogen for conducting interviews with stakeholders and operators of safety-critical systems. It introduces a step-by-step process that allows researchers and practitioners to conduct visual inquiries and early analysis of an unfamiliar domain. The article also theoretically explains and discusses the use of sketching and visual representation to uncover tacit knowledge and hidden processes. This particular way of conducting interviews and early analysis was the method employed in the studies described in the two following articles.

1.5.2 The use and evolution of design methods in professional design practice

The second article describes how professional design practitioners at Halogen use design methods in safety-critical systems (Schønheyder & Nordby, 2018). This in-situ study describes in depth how a design method is pragmatically and consciously adapted to fit the situation at hand. This description contrasts current design literature on how design methods are used in professional design practice. The article includes a model for describing how these adaptations repeat in cycles during a project and contribute to the evolution of the design method. Drawing on established theories, the articles proposes a framework for consistently evaluating and evolving a design method in practice. The findings from this study provided the framework for the third study.

1.5.3 Designing Relevant Methods: A Case Study on Iterative Method Development in Professional Interaction Design Practice

The third article seeks out to investigate whether relevance might be maintained by applying research rigour to methods that have been developed in a design practice (Schønheyder, in review). It presents an in-depth account of a 12-month long method development process in a commissioned project for a safety-critical system. In this account, the process of

translating unfamiliar situation awareness theory (SA) into practical design heuristics is described. Through an iterative explanation building process the findings are used to propose a conceptual framework real-world method development. The conceptual framework has the potential for practitioners to improve integrity and relevance in own design methods.

1.6 Contributions

The main contribution of this thesis is a current understanding on how design methods is used in an authentic setting, and new frameworks to improve relevance and integrity for design methods aiming to support professional design practitioners. Subsequently, this thesis provides new possibilities for practitioners and researchers to interact in the space between theory and practice.

First, this thesis contributes with the model, pragmatic and disciplined ways. A model to illustrate the current situation on how methods are used and developed in professional design practice. The material in the model explains in depth how design methods are used to tackle unfamiliar situations and generate arguments in the design of safety-critical systems. Further, the material provides a current explanation how a disciplined approach is accompanied by pragmatic and designerly ways of doing and knowing in a real-world context. The material presented in this contribution draws on established interaction design and HF literature. In line with pragmatism, this provides the larger context of the current situation. Thus, the model can contribute to new opportunities for practitioners and researchers aiming to improve and develop new methods, relevant for design of safety-critical. Subsequently, this may be of general interest to researchers interested in the transition of interaction design into the field of safety-critical systems. In Halogen, this framework functions as a foundation for the Halogen Design Method Collection (HDMC). The HDMC was developed as a part of this research to provide practitioners in Halogen with methods to support the translation of analysis to concept designs for safety-critical systems (Figure 3).

This thesis additionally proposes a framework that could improve the relationship between design practitioners and researchers. This framework combines a modified interaction design research triangle that incorporates pragmatism to create a tool for designers and researchers to describe real-world problems together. These problems can be described through sketches and visual representations on a common surface. Framed by the primacy of practice principle, these representations can then be used as tools to guide actions and reach goals. Subsequently, knowledge can be derived through symbolic representation of concepts, relationships and simplification of complex information (Worren, Moore, & Elliott, 2002). I would propose that improving the connection between researchers and practitioners is increasingly important for establishing interaction design practice and interaction design research in the field of safety-critical systems.

Overall, the contribution of this thesis may benefit both researchers and practitioners in understanding and developing design methods that are relevant for everyday design practice. As a long-term goal, I hope that the contribution of this thesis may help create a shared space between practice and research to further improve design methods for

safety-critical systems. It is my hope that this shared space may positively impact society at large by minimising the risk to humans, the environment, and the economy.

Figure 3. Design practitioners in Halogen using the SA method card developed in this thesis to evaluate a concept for remote airfield towers. Photo credit: Jan Fredrik Schønheyder

1.7 Conditions of the study

This research was conducted as an industrial PhD in the design company Halogen, where I am also currently employed. The industrial PhD scheme was developed by the Research Council of Norway to enhance interaction between academia and industry (The Research Council of Norway, 2010). This means that the research is placed as close as possible to practice.

Halogen is a 17-year-old multidisciplinary firm with 60 employees, based in Oslo and Stavanger, Norway. The company has national and international clients and a multidisciplinary team of 54 designers and developers from the fields of industrial, service, and interaction design as well as psychology, engineering, and anthropology. Its projects vary from interface design for desktop applications to strategic concept development and include integrated interaction and industrial design of control rooms. The company uses the human-centered design process (ISO 9241-210, n.d.) and is inspired by the design company IDEO´s processes (IDEO.org, 2015). Therefore, Halogen has divided their design process into three main phases: insights, concepts, and design (Figure 4).

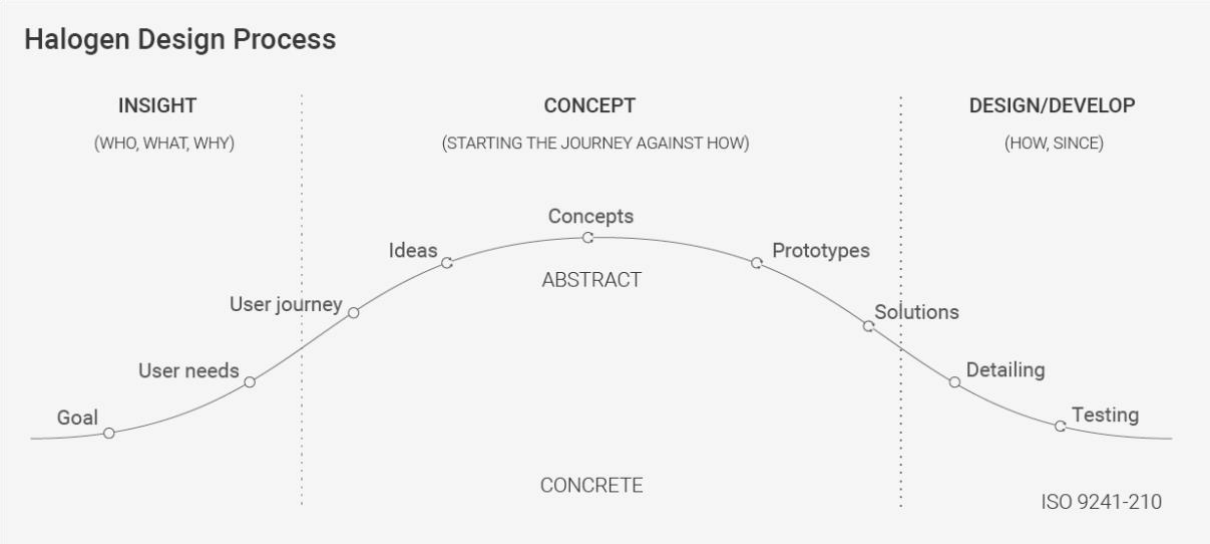

Figure 4. Halogen´s human-centred design process.

Since this study addresses design practice, all research activities took place in an authentic field setting. As mentioned, I was part of a design team developing a concept operation room for future Norwegian submarines. By Norwegian law, the project is classified as confidential, and I am not allowed to speak or reveal specific information about the project. These constraints must be observed in this thesis. Therefore, this thesis focuses on the process and the activity of developing methods, rather than the content of developed methods or the finished designs.

Figure 5. The author as both researcher and designer aboard the submarine KNM Uredd*. Photo credit: Jan Fredrik Schønheyder.*

As an industrial PhD fellow working in *design practice,* I had two roles, one as a researcher and one as a practicing designer (Figure 5). According to Fallman (2008), such a dual role is primarily synthetic due to involvement in a particular design situation. Subsequently, this form of design research has several implications for understanding rigour and relevance (Fallman & Stolterman, 2010). As Bruce Archer (1995) argues, it is nearly impossible to conduct a systematic enquiry of the real world and at the same time to avoid investigation contamination and interference. In an effort to address this challenge, I have systematically combined and triangulated multiple research methods and theories. Such an approach has the potential to overcome inherent biases and help make assumptions explicit (Creswell, 2013; Goodman et al., 2011).

1.8 Structure of the thesis

This industrial PhD projects uses a thesis by compilation model. This means that the thesis combines three articles with an overarching theoretical background and summary of the main research (Morrison, 2017).

The thesis is divided into two parts (Figure 6). The first part presents the research context, the main findings from the articles, and the research approach used in this study. The contribution of the thesis is also identified. In this manner, this thesis aims to weave together the threads of new knowledge and research reflections into one overarching discussion (Morrison, 2017). The second part includes the three articles that, together, comprise the current study of design methods in the context of professional design practice.

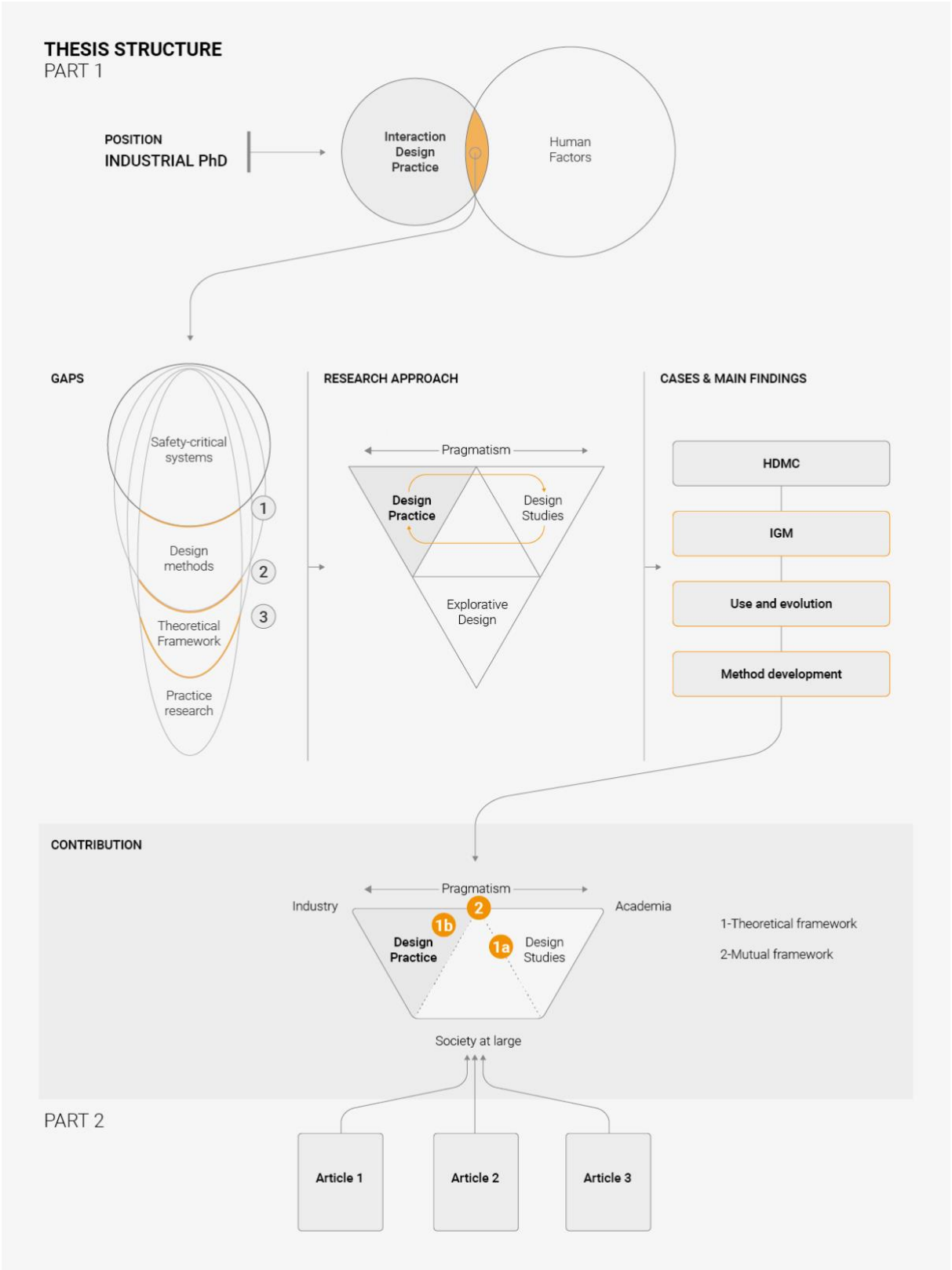

Figure 6. The structure of this thesis.

2 THE CONTEXT OF THE STUDY

This chapter positions the research and determines its contribution by describing previous literature and material in the context of an industrial PhD. It was important for me to identify and address the different implicit and explicit factors that influence everyday professional design practice. However, this is not an exhaustive account; it is a review of the key literature in the area of interaction design practice and Human Factors. My motivation for this approach is to begin with a transparent understanding of the implications and significance of this research.

First, I will introduce my objectives and approach for conducting a literature review. I will then present my research position and the context for this study in a review of design practice, after which I will review Human Factors. The philosophical worldview of pragmatism is then introduced to further position the research. The literature review establishes a multidisciplinary theoretical framework for identifying gaps in the literature and developing research questions. These questions are introduced in the next chapter ('Problem Statement and Research Questions').

2.1 Objectives of the literature review

The objectives of the literature review and the approach used for it are described below.

Sharon Poggenpohl (2012) states: 'Design research starts with what we don't know but would be valuable to know.' Motivated by this statement, the overall goal of this review is to offer a broad understanding of existing knowledge and to identify the implications and potential values of the intersection of design practice and Human Factors (Figure 7). Due to the nature of this industrial PhD and drawing on research as design practice, three primary objectives have guided this literature review:

1. The study should address challenges that Halogen's practitioners face in commercial projects, such as the design of safety-critical systems.
2. The study should identify challenges that are important for both Halogen and design research.
3. The study should help position, inform, and explain the creation of design in this particular real-world context.

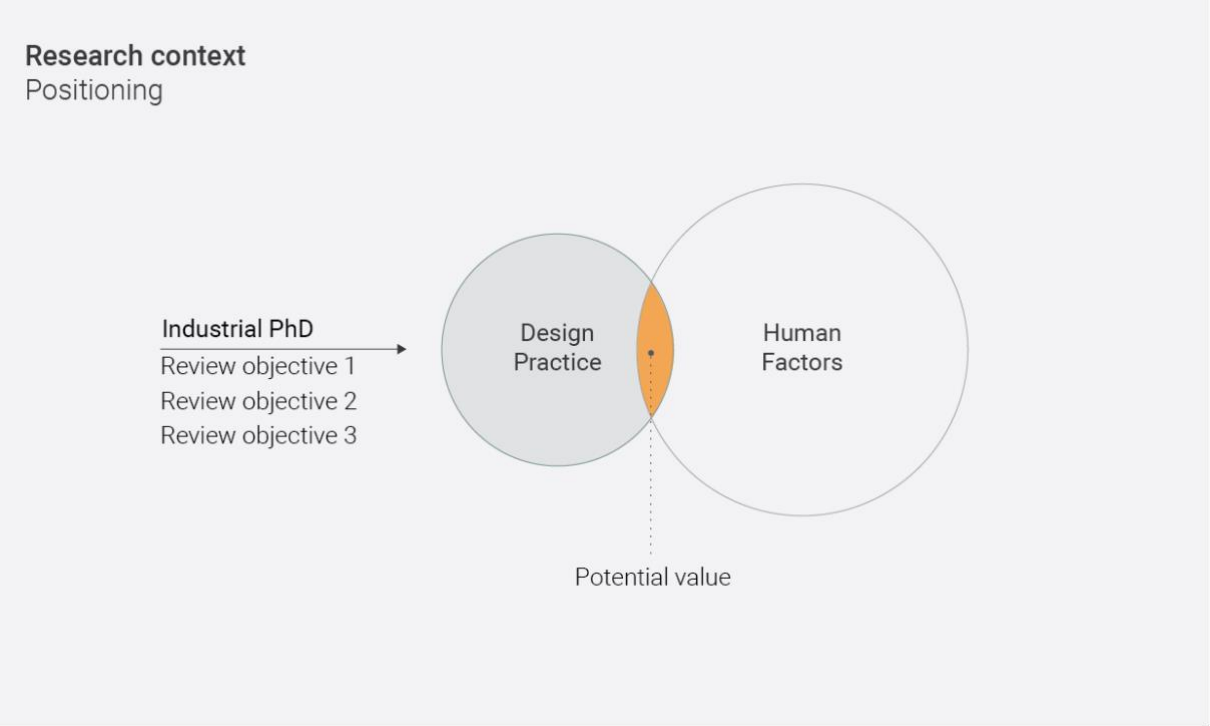

Figure 7. Research context and objectives for the literature review.

2.1.1 Strategy and approach

The strategy used here to conduct literature reviews in two disciplines draws on Poggenpohl's (2012) recommendation to identify something that would be valuable to know on my research topic. This suggestion encouraged an approach that was structured and methodological but also organic and explorative to allow me to discover what I don't know.

The literature review was conducted using several tools and overlapping techniques to uncover knowledge that may be obscured from the perspective of a particular discipline. It included:

- A study of seminal literature in the two domains, such as 'Designerly Ways of Knowing' by Cross (2006) and 'Introduction to Human Factors Engineering' by Wickens et al. (1998)
- Open searches of key words and phrases for each discipline on internet search engines such as Google Scholar, BiBsys, and Wikipedia
- Advanced searches in journals specific to each domain and discipline, such as *Design Studies*, *Human Computer Interaction*, and *The International Journal of Design*
- Personal inquiry with authorities and scholars in both domains
- An historic tracing of theoretical discourses and topics
- Drawing on personal experience to expand the search of particular aspects of design practice

Some of the key words used on the search engines were:

- Argumentation
- Concept
- Creativity
- Design

- Generation
- Heuristics
- Idea
- Judgment
- Practice
- Professional
- Reflection
- Visualisation

With open and advanced searches, one particular topic could be searched repeatedly using different discipline-specific phrases, abbreviations, and terms (Table 1).

Some of the search words, abbreviations, and phrases used in the literature search.

DESIGN PRACTICE	HUMAN FACTORS
Innovation Processes	Development processes
Interaction Design	Human computer interaction / HCI
Interface Design	Human machine interface / HMI
Interface Design	Man-machine interface / MMI
Prototyping	Tool development
Risk	Criticality
Screen Based Information	Graphical user interface / GUI

Table 1. Different discipline-specific phrases and abbreviations for related key words.

The collected literature was consecutively classified and organised into domains, fields themes, topics and discourses using the referencing tool Zotero and visual mapping techniques from systems oriented design (Sevaldson, 2013) to create an overview and understanding of the developing framework.

Patterns, dependencies, unknown relations and gaps in the literature was identified on these maps by drawing on iterative explanation building (Yin, 2013) techniques. The result was several visual maps consisting of cards with image of author, field of expertise and contribution. The cards were utilised to build several types of maps such as hierarchical domain specific structures, chronological timelines and also visual structures of the literature review (Figure 8).

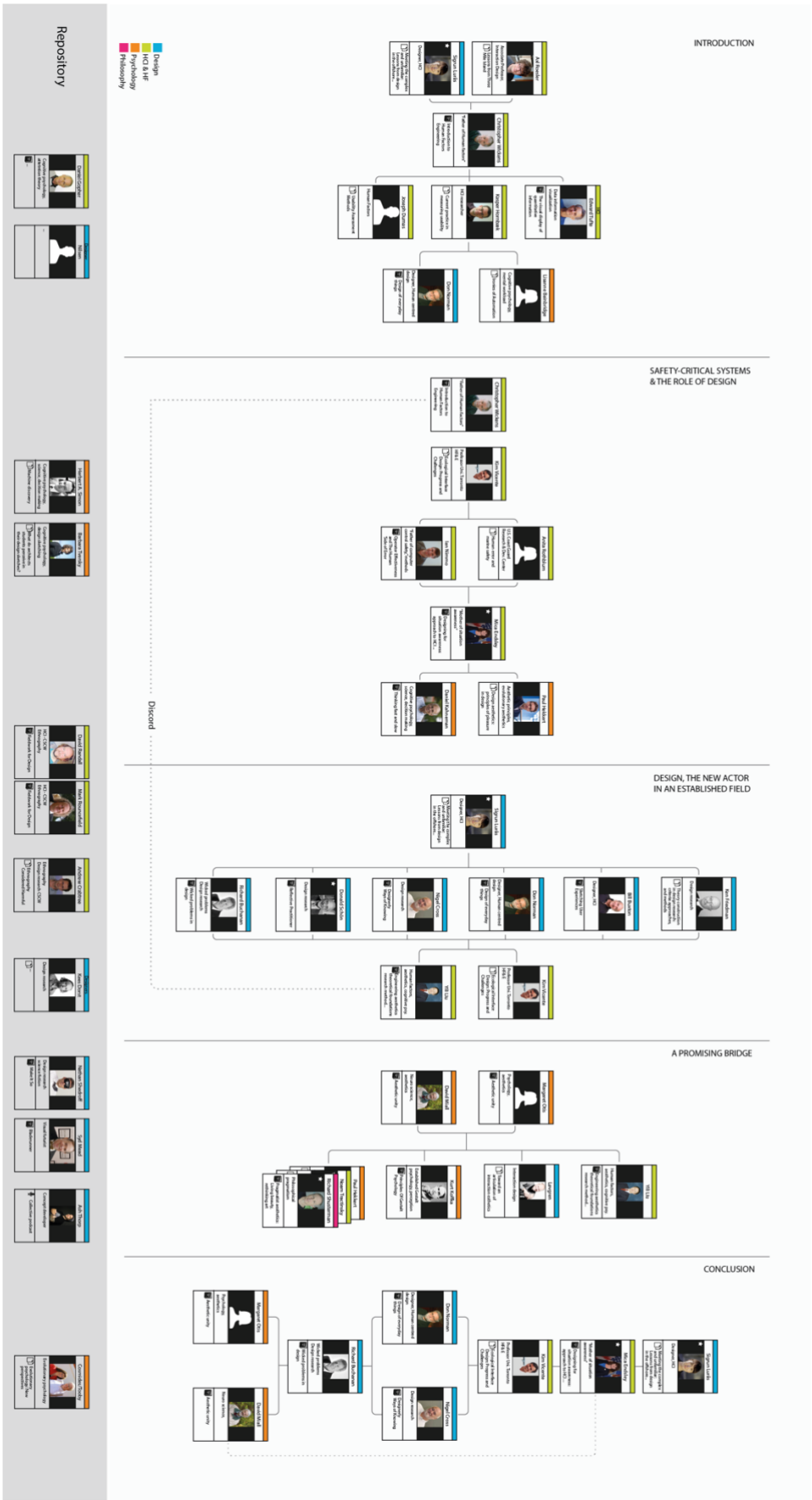

Figure 8. An example of a map displaying the research context, structure, and authorities in this thesis.

2.2 The research context

This section describes the position of this thesis in the context of professional design practice. It then presents an overview of Human Factors in relation to the design of safety-critical systems.

2.2.1 Design research and professional design practice

To position interaction design practice within the discipline of design, this first section provides an overview of the tension between design research and design practice.

In general, design includes a large spectrum of activities, disciplines, and philosophies. They all share the aim of making sense of something new and different from what was there before (Krippendorff, 1989). The word 'design' has several meanings, ranging from abstract concepts, processes, and plans to achieve something new (Giacomin, 2014). Furthermore, 'design' is both a noun and a verb and can refer to either the process or the end product. This means the word can have quite different meanings depending on the background and particular position of the person using it (Lawson, 2005). Buchanan (2001) states that the different opinions on the definition of design are actually a strength that prevents the field from becoming stagnant. Buxton (2007), on the other hand, sees it as a problem that the meaning of design has been diluted and unclear in literature and practice. He argues that 'when a word means almost anything and everything, it actually means nothing' (Buxton, 2007, p. 95). Of his own position and definition of design, Buxton talks about 'down and dirty' design for a messy and constantly changing real world. So, what does this mean in the context of my research?

Numerous studies on real-world design and professional practice support Buxton's depiction. The study of professional design practice has been an ongoing discourse in design research over the last fifty years. It can be traced back to important texts such as Bucciarelli´s (1994) study of engineers at work, Schön's (1983) work on designers' reflective practices, and Cross's (2001) and Lawson's (2005) discussions of how designers think and act. This discourse even dates back to Jones's (1970) and Archer´s (1965) studies of methods in design professions. Although the study of design practice has been ongoing, in recent years, this area has seen a new focus and increased enthusiasm (Luck, 2012).

However, it has been argued that most of this research draws on an academic conception of practice, not on how practitioners actually work (Gray, 2016). This issue has been especially evident in Human Computer Interaction (HCI) and interaction design research. Contributions such as Rogers's (2005) study on design methods in practice, Buxton's (2007) work on complex design situations, Goodman et al.'s (2011) work on understanding interaction design practices, and Grey's (2016) study of the mindset of practitioners are examples of studies that have raised and addressed this concern. Stolterman´s paper, 'The Nature of Design Practice and Implications for Interaction Design Research' (2008) offers a more nuanced understanding of design practice. His discussion of design complexity, judgment, discipline, and rigour in real-world practice laid the groundwork for multiple new studies and theoretical frameworks (Goodman et al., 2011; Gray, 2016; Höök & Löwgren, 2012; Zhang & Wakkary, 2014). I will return to Stolterman´s paper later in the literature review.

It is important to be aware of the tension between research and practice in design since this conflict can shed light on misunderstandings and confusion in proposed research strategies and methodologies.

2.2.2 Complexity in interaction design practice

In the context of my industrial PhD project and Halogen´s strategic focus, the following sections will further explore interaction design practice and the nature of design.

The term *interaction design* was first coined by industrial designers Moggride and Verplank when they were working on the first laptop computer, the Grid Compass, in the mid-1980s. They were inventing a way for people to interact with computers and created this term to explain what they were doing. Over the last three decades, interaction design has borrowed practices from other established design disciplines, such as industrial and graphic design, but has also evolved beyond them (Cooper, Reimann, & Cronin, 2007).

Drawing on Moogride, Cooper et al. (2007) suggest that interaction design consists of three overlapping concerns: form, content, and behaviour. This means that interaction design involves the design of behaviour in relation to form and content. For example, content is structured, accessed, and presented in a specific form to support a specific behaviour. In Cooper et al.´s model, this includes professions such as information architects, animators, and graphic designers (Figure 9). On the other hand, Saffer (2009) describes interaction design as a stew of disciplines that is still trying to find its place among neighbouring fields such as information architecture, user experience, HF, and human-computer interaction (HCI). Löwgren (2013) later suggested that interaction design covers only a small part of the HCI field. I will return to HCI later in this chapter.

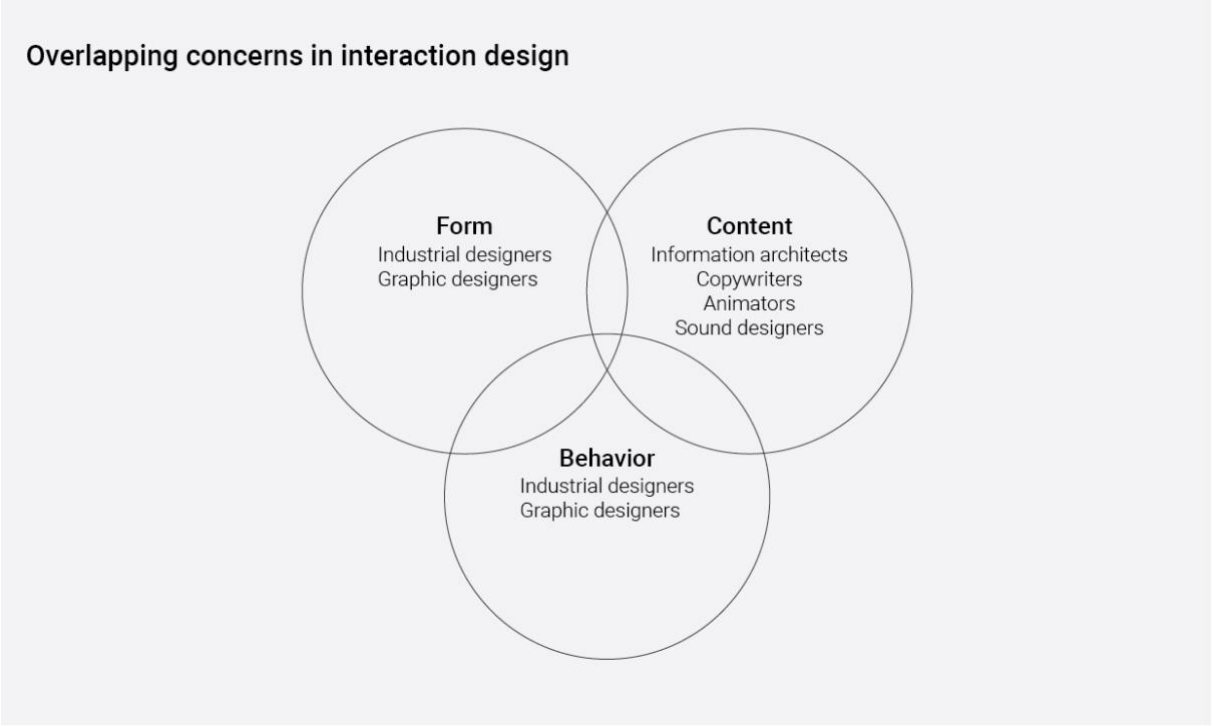

Figure 9. Cooper et al.´s overlapping concerns in interaction design. Figure made by the author.

To frame interaction design in the context of design practice, interaction design can be defined as a complex discipline dealing with the specification of digital behaviours in response to mechanical or human stimuli (Goodman et al., 2011). In real-world situations, interaction design practitioners combine their knowledge of potential users and of systems in action with technological possibilities and aesthetic judgment to achieve a specific behaviour (Moggridge, 2007). However, the aspect of practice in a real-world context retains particular characteristics and mechanisms that additionally influence and implicate a design process. Before discussing Stolterman´s nature of design, I will first attempt to clarify the word 'practice.'

There is a rich body of work that seeks to define practice and professionalism in design. Cetina et al.'s (2001) exploration of practice theory, Lawson´s (2005) historic work on the professionalisation of design, and Green´s (2009) understanding of professional practice are some examples of seminal work that have influenced the understanding of 'practice' in design research. However, much of the existing literature on practice theory is outside the scope of this PhD project. I will nevertheless outline how practice is perceived in the context of interaction design research.

First of all, professional practice can be seen as a composite of three aspects: what practitioners do, what they experience, and where these actions take place (Green, 2009). Goodman et al. (2011) describes this composite as professional design activities intended to create commercial products in a real-world context. Drawing on practice theory, Kimbell and Street (2009) expand this composite by stating that interaction design practice is carried out by individuals, but organised collectively. This means that activities, experiences, and contexts must be seen, not only as individual events or things, but also as a technical system that includes organisational structures, tools, and knowledge (Cetina et al., 2001). Stolterman (2008) uses this conception of practice when discussing the nature of design.

Stolterman's (2008) main argument is that the research community needs to recognise and accept design complexity as a real, practical problem. These are problems that professional designers face in their daily practice. He points out that, in the real world, design complexity cannot be addressed using scientific methods, tools, and approaches. Instead, design disciplines and practices need to develop and adapt their own approaches (Stolterman, 2008). He argues that design complexity is almost the opposite of science. Where science focuses on the universal and existing, design deals with the specific, intentional, and non-existing. Stolterman discusses five preconditions and goals that distinguish design from science:

1. It is about creating *something* in the world.
2. That something is for a specific *purpose* and *situation.*
3. That purpose and situation are defined by a specific *client* and *user.*
4. That client and user needs that something to have specific *functions* and characteristics.
5. That something needs to be created within a limited *time* and with limited *resources.*

Drawing on the work of Krippendorff (1989) and Buchanan (1992), Stolterman (2008) further argues that design practice is about creating a desired reality manifested as an ultimate particular. By this, he means that design occurs when a unique artefact is created at a

specific point in time by a specific designer within a specific commercial situation. This implies that designers must understand the various needs and desires of both clients and users while managing limited time and resources (Stolterman, 2008).

The design work described in this thesis was done within these constraints and in such a situation. Buchanan (1992) states that in such situations, 'wicked problems' can occur.

2.2.3 Wicked problems in design

The term 'wicked problem' refers to a specific type of situation with certain constraints. Its presence and occurrence are known for implicating both design processes and research approaches.

First coined by Rittel and Webber (1973), the term 'wicked problem' was first used to discuss scientific engineering approaches that could not be applied due to problems in social policies. Also called 'ill-defined problems,' wicked problems are defined by high degrees of uncertainty; by loosely formulated scopes, constraints, and personal ambitions; and by their dependence on the viewpoint of individual actors or stakeholders (Buchanan, 1992). Coyne (2005) adds that wicked problems mostly occur in some practical context where there is no ultimate test of a solution's validity. This means that a design commission can be difficult to solve within the specified time and cost, due to incomplete knowledge, differing client opinions, and hidden problems.

When tackling wicked problems, Buchanan (1992) suggested that designers use their ability to think and explore systematically to understand the problem more clearly. Coyne (2005) argues that the objective of this systematic exploration is to make the hidden processes explicit and expose them through visual methods and diagrams. These approaches correspond with the design literature that describes a designer's ability to quickly visualize, generate, and reflect on multiple potential solutions to a problem (Buxton, 2007; Lawson, 2005; Schön, 1983). In such an approach, Donald Schön´s (1983) concept of reflection-in-action is a core intellectual process. The concept is described in his book *The Reflective Practitioner* (Schön, 1983). Following the theories of John Dewey, it is considered as a seminal book on reflective theory. Currently it is the most frequently cited work in the journal *Design Studies* (Beck & Chiapello, 2017). In this book, Schön (1983) state that reflection-in-action describes how designers draw on past experiences in a kind of conversation with a situation while simultaneously working on the problem. During reflection-in-action, 'as he [the designer] tries to make sense of it, he also reflects on the understandings which have been implicit in his action, understandings which he surfaces, criticizes, restructures, and embodies in further action' (Schön, 1983, p. 50). Using Schön´s definition, Stolterman (2008) states that Schön managed to provide design practitioners with intellectual tools for design without providing a detailed or prescribed process.

As mentioned, Schön follows Dewey´s theories on reflective practice. In Dewey´s (2005) lectures from 1932, he states that visually experiencing and reflecting on a problem can be a pragmatic response (Dewey, 2005). Dewey (2005) argues that such an approach intrigues us to better judge and evaluate the situation at hand. Here, the tacit qualities of sketching or building an aesthetic model can further generate discursive interventions, verbal explanations, and formulaic responses to a problem (Coyne, 2005).

As defined by Polanyi (2009), tacit knowledge is an understanding that cannot be explained in words but is communicated through practice and can be observed.

Norman (2013) further claims that good designers never try to solve the problem that is given to them; rather, they try to understand the underlying real issue. Norman (2013, p. 218) goes on to explain: 'As a result, rather than converge upon a solution, they diverge, studying people and what they are trying to accomplish, generating idea after idea after idea.' So, instead, of starting to work on a specific problem, designers ignore it and generate new issues to consider (Norman, 2013). He explains this in the context of human-centred design, which seeks to ensure that the result fits human needs, desires, and, most importantly, capabilities. Design involves thinking broadly about what the underlying problem is and then iterating and expanding on it before converging on a proposal. Norman calls this *design thinking* (Norman, 2013). Although design thinking presents numerous possibilities for discussing what design is and can be, the vast body of literature and discourses on this topic is too large to discuss in this PhD project. As Kimbell points out, 'Even on a cursory inspection, just what design thinking is supposed to be is not well understood, either by the public or those who claim to practice it' (2011, p. 286). However, I will present a short outline of design thinking in an effort to further examine designers' potential in relation to wicked problems.

The term 'design thinking' has been widely used in design research since Rowe used it in his book in 1987 (Rowe, 1991). However, the notion of design thinking can be further traced back to the works of Schön (1983) and Jones (1970). Since then, it has come to be seen as a new paradigm for dealing with problems beyond design (Dorst, 2011). At its core, current design thinking is about adopting a design practitioners' approach to problem solving outside the field of design, most notably in information technology and business (Brooks, 2010; Martin, 2009). Brown, the CEO of the design company IDEO, has been one of the more notable authors to present the general characteristics of design thinking for non-design communities (Brown, 2009). So, design thinking is not only a strategy for designers; it is also a practice for all innovators, poets, scientists, and engineers (Norman, 2013). Although design thinking has been introduced in other domains, Norman (2013) advocates designers because of their pride in innovation and their ability to explore creative solutions to fundamental problems.

According to Norman (2013), a designer's method of innovation can be condensed into four stages: (1) observation, (2) visual idea generation, (3) prototyping, and (4) testing. These four stages are iterated cyclically until a satisfactory proposition is designed. According to new studies in pragmatism, this process can help minimize uncertainty in a project and can support inquiry into the project's scope and goals through visual and generative speculation (Coyne, 2005). However, Coyne (2005) also emphasises that such a design process does not explicitly clarify the project's intention, target group, or consequences. He further argues that much work remains to be done to understand inquiry into wicked problems, and that problem-solving tools need to be developed for such situations.

If we accept Coyne´s argument, one can propose that there is a gap in the existing methods and tools for exploring and understanding wicked problems in design. This suggests that there are no formalised approaches for this thesis to draw upon in tackling wicked problems

in real-world contexts.

2.2.4 Pragmatic and designerly ways

There are however other alternatives for addressing real-world problems and constraints. The following section introduces pragmatism as a potential way for this thesis to navigate such design situations.

In response to wicked problems, Schön (1983) developed his own approach for solving problems that are not 'solvable' in design. Schön (1983) proposed that design is not just about 'problem solving' but also 'problem setting.' This means that product development requires the realisation that understanding the problem and solving the problem are both fundamental to the design process. In an argument that is rooted in the philosophical tradition of pragmatism, Schön (1983) proposes that design is all about 'messy situations' where traditional scientific principles can do more harm than help. Dalsgaard (2014) presents a bit more nuanced comparison. He suggests that where scientific traditions aim to formulate universal knowledge and to mirror reality, pragmatic philosophy sees thought and knowledge as tools for solving problems in a changing world. In this context, the pragmatic philosopher Anders Lindseth (2014) proposes that knowledge does not imply something is true or false; knowledge is defined by our 'ability to answer.' This means that the goal is to investigate knowledge in order to improve it. I find this viewpoint interesting in regard to design and problem solving for messy situations. Recently, Dalsgaard (2014) connected pragmatism with design thinking by illustrating how pragmatism can prompt a systematic understanding of a design situation. Such an understanding can be used to influence the design process and iteratively conceptualise an artefact. Dalsgaard (2005) further explains how Schön (1983) and Buchanan (1992) explicitly draw from pragmatism to understand and transform a design situation in practice.

'Wicked,' 'messy,' and 'changing world' are, as previously mentioned, expressions that scholars such as Buxton (2007) and Stolterman (2008) use to describe the real world of design practice. However, skilled designers can handle such problems and complexity, which has led to surprising innovations and well-designed solutions that incorporate functionality and aesthetic appeal (Stolterman, 2008). So, how do designers approach and practice design in messy, wicked situations? Cross (2006) uses the term *designerly* to explain approaches and ways of knowing that are distinctly different from recognised scientific or scholarly ways of knowing. Drawing on Lawson´s (2005) studies on how designers think, Cross (2006) defines designerly approaches as problem solving through synthesis by learning about the nature of the problem and trying out various solutions. This approach is driven by a designer's constraints to produce a practical result within a specific time limit. These constraints force designers to have the self-confidence to define, redefine, and address a problem in light of the situation at hand (Cross, 2006). In pragmatism, a designerly approach is called an experimental process. The definition, however, is similar to Cross´s: Designers draw on all available resources to inquire and develop their own understanding of the situation in order to transform it (Dalsgaard, 2014).

Although Dalsgaard points to pragmatism as a potential connection between wicked problems and designerly ways of doing, he is hesitant to propose practical approaches for real-world contexts. So, almost a decade after Coyne´s (2005) call for problem-solving tools,

the need is still unresolved. I would suggest that this is a significant gap for this thesis to address.

2.2.5 Instrumental judgment in design

To further understand the potential role of designerly approaches in this thesis, we need to unpack the term in relation to design practice.

The body of literature on designerly ways of knowing has grown in recent decades, and in the process, new, important aspects of design practice have been uncovered. According to Goodman et al. (2011), design rests on a form of knowledge that differs from conventional scientific knowledge; skilled design practitioners value reflexivity, interpretation, and judgment above intellectual objectivity. Therefore, design reasoning can be seen as an artistic or improvised approach to the particular which can only be located in action, an approach that is often called 'situated reflection' (Kimbell & Street, 2009; Moggridge, 2007; Schön, 1983). However, Stolterman (2008) adds that using reflexive intuition as a precise intellectual tool in the right situation for the right purpose is extremely difficult and demanding for a designer. The designer's *judgment* must be the primary tool for designerly approaches to wicked problems and design complexity (Stolterman, 2008).

Nelson and Stolterman (2012) further developed the idea of design judgment into instrumental judgment when discussing holistic design approaches in unpredictable worlds. Instrumental judgement requires not only a mechanical understanding of a situation, but also experienced-based knowledge of the appropriate action and the potential value of that action. Instrumental judgment does not result in reconciliation, resolutions, or trade-offs; it produces individualised outcomes that facilitate the development of a design in a given situation (Gray, 2016; Nelson & Stolterman, 2012). However, Gray et al. (2014) claim that this process is not well understood and can only be observed amongst master designers. They suggest that professional designers should be observed *in situ* if one seeks to understand the richness and complexity of design practice and to understand instrumental judgment (Gray et al., 2014).

The term *in situ* refers to the site where the actual creation takes place. Because of this thesis's approach to research as design, I have unique access to the actual designing process. The lack of *in-situ* knowledge represents a significant gap for this thesis to address.

2.2.6 Design methods in professional practice

To clearly identify this gap, the following section discusses existing research on real-world tools and methods in design practice.

The call for *in-situ* research on professional design practice has been a recurring topic in interaction design and HCI over the last decade (Goodman et al., 2011). Although several attempts have been made to conduct this kind of research, there is now a problematic gap between research and practice in design (Gray, 2016). The gap was first identified by Rogers in 2005 when studying practitioners in the UK and US (Rogers, 2005). She discovered that methods developed in research to support practice were seen as too theoretical and not that accessible for use in real-world settings. As a result, these theoretical methods were not used by practitioners (Rogers, 2005). Another aspect of this gap between theory and

practice is that researchers assume that professional designers tackle real-world complexity using scholarly, scientific methods (Stolterman, 2008; Wakkary, 2005). The gap has led to an increased interest in understanding practicing designers on their own terms (Dickson & Stolterman, 2016; Goodman et al., 2011; Gray et al., 2014; Lallemand, 2015). New theoretical foundations for researching and discussing design practice have been laid (Goodman et al., 2011), and design research has the beginnings of an understanding of how design methods are developed and used in professional design practice.

In recent studies of design practice from a practitioner's perspective, researchers have found that design practitioners often pragmatically develop and adapt their own methods by trying and discarding ideas to fit the needs of the practice or the current situation, such as time constraints, available resources, and specific client demands (Dickson & Stolterman, 2016; Goodman et al., 2011; Gray et al., 2014; Lallemand, 2015). In this thesis, the term 'design methods' refers to tools, approaches, frameworks, and techniques that either provide step-by-step instructions or a framework of thinking to support a design process (Dickson & Stolterman, 2016). Design literature emphasises that such frameworks and approaches, which are found in interaction design, can be especially useful for creatively generating new ideas to highly complex challenges (Buxton, 2007; Cross, 2007; Lawson, 2005). Although there are a multitude of formal techniques and methods that support such a process, there are also highly unstructured, informal approaches, and design practitioners select from all of these (Stolterman & Pierce, 2012). As Gray (2016) explains, practitioners select, use, and develop methods due to instrumental knowledge. Another point Gray makes may explain how designers adapt and think about methods in their surroundings. As one of his interviewees said, 'It's more of a mindset than a method' (Gray, 2016, p. 4051).

Although this statement was published in 2016, it represents a longstanding concern. Rogers's (2005) original concern was the fact that most design practitioners are not scientifically trained. As a result, it may appear that practitioners do not know about or lack interest in rigorous use and knowledge of a specific method. Although research has suggested a wide range of methods that can instil rigour in a design process, these methods are seldom used in practice. The reason for this is often their lack of applicability to real-world situations (Goodman et al., 2011; Gray et al., 2014; Rogers, 2005).

Furthermore, it may be inappropriate to compare scientific rigour with rigour in practice, a question that has been widely addressed in design literature (Cross, 2006; Lawson, 2005; Sevaldson, 2010; Stolterman, 2008). Scientific rigor is optimised to produce knowledge, and this differs to design practice. Bartneck (2007) explains that, in design, rigour means creating artefacts that tend towards simplicity; it means finding the least complex solution to achieve a goal. Fallman and Stolterman (2010) further suggest that, if a final design is relevant (meaning it makes sense and is useful), then rigour is less of an issue.

However, what happens when the established role of design transitions into a new domain that is unfamiliar with designerly ways of doing and with instrumental judgement? What happens when design enters a domain where the concept of rigour and explicit methods and approaches are deeply rooted in scientific disciplines? These questions address one of the core concerns in this thesis. This concern involves the emerging role of design practice in the context of the design of safety-critical systems. The scientific discipline of HF resides in this

context. The next section will review this transition in more detail to explain how it affects design judgment, tools, and methods.

2.2.7 Design in unfamiliar domains

Lurås (2015) has already discussed the new, emerging role of designers in high-risk domains. Lurås describes a growing trend; designers are working more often in new, unfamiliar, complex fields, such as the offshore industry. Products and systems developed for offshore operations can be regarded as a safety-critical system.

As mentioned in the introduction, Knight (2002) defines safety-critical systems as systems whose failure could result in loss of life, significant property damage, or damage to the environment. Today, many modern information systems are becoming safety-critical in a general sense because financial loss and even loss of life can result from their failure (Knight, 2002). From personal experience, I would also add that the professional users and operators of safety-critical systems are responsible for complex systems in which they execute specific tasks and workflows, often in demanding work environments (Figure 10). Unlike consumer technology, working in these systems also requires employment, training, and certifications.

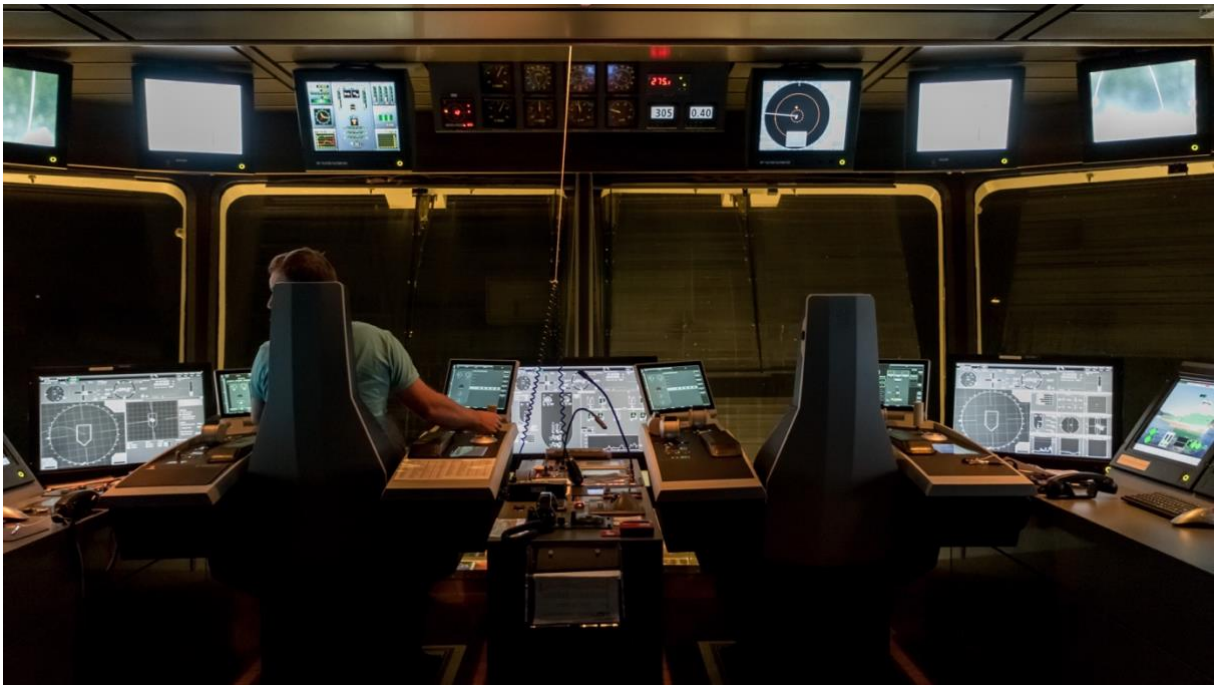

Figure 10. Operator using designs by Halogen during night-time operations. Photo credit: Peder Torget

Until recently, safety-critical systems were considered outside the field of design. According to Lurås (2015), traditionally, the offshore industry has developed products without assistance from industrial or interaction designers. This is one reason why, in offshore projects, the designer's role is often unclear and the scope of the project is difficult to define (Lurås et al., 2015). However, these issues must be seen in the context of the individual development cultures that resides in the industry. According to Lurås et al. (2015, p. 142), 'Previously, if designers were engaged they were mostly hired late in the process to "style" individual equipment, while now designers are more often involved earlier in the process and in projects with a wider scope: even the design of whole vessels and entire ship bridges.'

Lurås (2016) investigates these challenges and barriers and argues for a systemic approach in which insight and setting boundaries are key elements for designers working in unfamiliar fields.

The transition of a design profession into a new field is a central topic in this thesis. The transition of design professions can be observed in Buchanan's (2001) four orders of design: graphic design, industrial design, interaction design, and environmental design. With these areas, Buchanan provides a framework for discussing and rethinking the nature of design. However, these 'orders' also provide a background for how design has shifted in the twentieth century. In 2001, Buchanan explained that interaction design and environmental design were in the early stages and that it was unclear how they would transform design professions and education. He also stated that a central challenge is understanding how designers can transition to other fields and return with results that shed light on problems in design practice.

Friedman (2003) later argued that design plays a significant role in the evolution of new technology; this has given the design process a new meaning. Friedman explores how designers are increasingly taking on new, important tasks that were previously not considered a part of the field of design. While many of these projects are successful, design failures are also common. Freidman (2003) claims that these failures often share a lack of method and of systematic insight and comprehensive understanding. Consequently, this is due to gaps in preparation and knowledge. Friedman (2003) argues that it here theory and research play a role. In these gaps, theory can lay the groundwork for understanding how things work. Theory can also enable designers to analyse a project and explain their solutions – activities which, according to Friedman, are the purpose of theory. Friedman also (2003) argues that is not experience but the designer's interpretation and understanding of personal experience that is the source of new knowledge. He goes on to explain that knowledge emerges from critical inquiry, which occurs when systematic, scientific knowledge is extracted from the theories that allow designers to question and learn. Friedman also emphasises the service dimension of design, in which, he believes, art and science both contribute to design.

Buxton (2007) offers a more practice-based reflection on this topic. He discusses the role of the designer and how design fits in with other disciplines, such as engineering, marketing, and corporate plans and executive aims. Buxton argues, 'We are at one crossroad in the history of design, namely one where products are assuming complex dynamic behaviours that require new skills and approaches to their design' (2007, p. 418). In contrast to Friedman, Buxton points out that the designer's ability to envision and experience future possibilities can play a significant role in navigating in this new space.

Buxton´s ideas point to some important aspects that may help position the role of design in safety-critical systems in this thesis. However, research on this particular field is sparse, so there is little empirical data for this thesis to draw upon. Nevertheless, Lurås's (2016) contribution can provide some insights on how the design of safety-critical systems complicates traditional design practice.

2.2.8 Complications for design practitioners in safety-critical systems

The next section outlines design complications that play a role in this thesis.

As Lurås, Lützhöft, and Sevaldson (2015) show, industry has gradually begun to recognise the skills and value that design can add to development. In the past, if industrial designers were used at all, they were hired late in the process to 'style' individual equipment. Today, however, designers are involved much earlier in the process and can even influence the scope of projects. This gradual shift of designers entering the field of safety-critical systems increases the need for design practitioners to understand elements of the HF field, such as how human behaviour changes in critical situations. The challenge here lies in a design practitioner's lack of vocabulary and authority in advocating new designs to industrial stakeholders. As one of Lurås's interviewees said, 'To say "I just feel this is right" does not hold in these industries' (Lurås et al., 2015, p. 146). This comment refers to the rigorous safety requirements and standards that limit design solutions.

However, as Lurås points out, designers are also obliged to question requirements and use these questions as a starting point for creativity. Another interviewee argued that designers need to understand the purposes of the requirements so they can consider alternative ways of achieving the same thing (Lurås et al., 2015). This is also addressed in the book *Designerly Ways of Knowing* (Cross, 2006). Cross states that a client's briefs and requirements can often be vague, and the client's problem and criteria only become clear as the designer suggests possible solutions. In such a case, the designer's early conceptualisations and representations of the problem are critical to directing the course that leads to the final design proposal (Cross, 2006). Lurås refers to this when she discusses designing *for* and *within* the system, considering both the operator and the industry. This means that designers work within two intertwined systems: the operational system in which the design will be used, and the regulatory and organisational system governed by the client (Lurås, 2016)

These points raise a new question. If we accept that designers need to design *for* and *within* the system, would that suggest that the methods and tools they use need to be developed specifically for safety-critical systems? If so, then it is important to understand this and position the research in this unfamiliar domain. This thesis is positioned between safety-critical systems and design, allowing it to benefit from the strengths of both disciplines and compensate for their weaknesses. The following section reviews safety-critical systems in the context of HF.

2.3 Safety-critical systems

This part of the review has a different structure than the previous section on design practice. Here, my aim is to provide an overview of the framework, processes, and discourses from the 'unfamiliar' domain of HF. This framework and these processes and discourses shape and influence the design of safety-critical systems.

2.3.1 Accidents involving safety-critical systems

To understand the importance of design in safety-critical systems, I will first describe a pivotal accident; poor design was a contributing factor.

In March, 1979, the reactor cooling system of the nuclear facility at Three Mile Island in Pennsylvania, US encountered problems. Confused by the instrumentation panels, operators failed to mitigate the situation, triggering a new set of events that escalated the situation. As the pressure and temperature increased around the reactor, alarms started to sound in the control room. Within the next three minutes, over one hundred alarms sounded simultaneously. During these first critical minutes, the design of the information displays and control panels further confused the operators, negatively affecting their decisions (Roesler, 2009).

The chain of events that followed eventually led to the worst nuclear accident in US history. Unknown amounts of radioactive gases and radioactive iodine were released into the environment, and the risk of cancer in the population is shrouded by a lack of data and by illness classifications. After a twelve-year clean-up, the cost of the accident was about one billion dollars (US NRC, 2014). The post-accident assessment of Three Mile Island states that all information was available in the control room and that the accident could have been prevented if the operators had been able to detect the open valve, which should have been closed (Figure 11). However, due to poor design and poor emergency procedures, this mistake was not recognised and corrected at the time (Roesler, 2009).

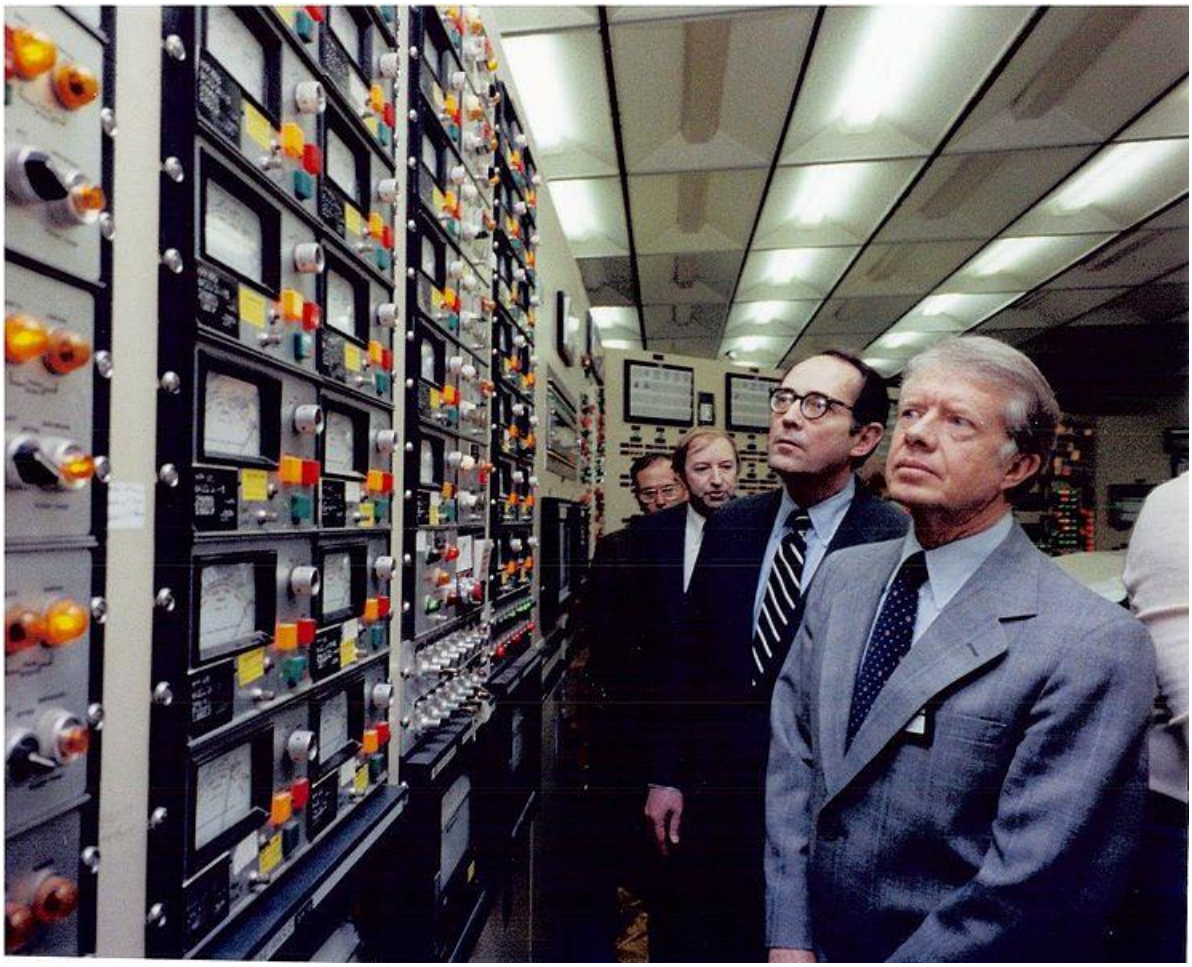

Figure 11. President Carter inspecting the aftermath in the TMI-2 control room. Photo credit: Wikimedia Commons

The Three Mile accident is not the only example of operator confusion caused by poor design. Another is *Deep Water Horizon*, oil rig owned by the British Petroleum (BP) that exploded in 2010. According to *The New York Times* (2010), operators froze because of the sheer complexity of the safety systems. One emergency system alone was controlled by 30 buttons. With over 20 flashing critical alarms, one operator began pressing buttons that told the system that the crew was aware of the alarms, instead of sounding the master alarm. The accident caused the death of eleven workers and the release of massive amounts of oil into the Gulf of Mexico. The total damages to the environment, the US Gulf Coast economy, and BP are estimated at $36,9 billion (Smith et al., 2011). Investigation reports later claimed that the design of the operating systems limited the operators' capability to respond in a stressful environment (Bly, 2011).

Unfortunately, design has been a contributing factor to numerous other accidents, such as the Überlingen mid-air collision, the grounding of the *Royal Majesty*, and the Jeep Grand Cherokee´s gear shift (Boumis, 2016; Masys, 2005; Rowley et al., 2006). However, the accident at the Three Mile Island in 1979 can be seen as a pivotal moment for the fields of HF and of human–computer interaction. It has become a reference point for understanding design errors and has contributed a large portion of what we know about design in safety-critical systems today (Roesler, 2009)

The field of HF may be the most significant contributor to current understanding of human behaviour and capacity in relation to critical and complex systems. HF has roots in psychology, engineering, ergonomics, and cybernetics and is considered the prime authority in developing and influencing safety-critical systems (Lurås et al., 2015).

To clarify HF's role in and contribution to this thesis, the following sections outlines the background, core theories, and critiques in this multidisciplinary domain.

2.3.2 Human Factors

HF includes an immense body of literature on research, theory, and practice related to safety-critical systems. It would be unrealistic to attempt to cover the entire domain in this thesis. I will, however, review topics in HF that overlap with or border interaction design practice and methods in an effort to further position the thesis.

As briefly described in the introduction, HF is a large scientific field that, in addition to the above-mentioned disciplines, includes domains such as physical ergonomics, cognitive ergonomics, and organizational ergonomics. Rothblum (2000) describes HF as a discipline that is devoted to understanding the capabilities and limitations of humans and to using this information to design appropriate equipment, work environments, procedures, and policies. The specialised domain of cognitive ergonomics, which is relevant to this thesis, is concerned with the mental processes of systems interaction and of the development of design methods (Stanton, Salmon, & Rafferty, 2013). Cognitive ergonomics contributes an extensive collection of established methods such as cognitive work analysis, critical decision method, task-centred system design, and function analysis and allocation. A complete overview is available in seminal books such as *Introduction to Human Factors Engineering* (Wickens, Lee, Liu, & Gordon-Becker, 1998), *Human Factors Methods* (Stanton et al., 2013) and *The High Performance HMI Handbook* (Hollifield, Dana, Nimmo, & Habibi, 2008).

Although these methods were scientifically developed and are theoretically grounded, critical literature and reviews of these methods are scarce. However, critique concerning lack of applicability to real-world practice has been raised recently. Similar to design research, Shorrock and Williams (2016) discuss what they call the research–practice divide. In their experience as both researchers and practitioners, a remark often heard in academia is that practice is lagging behind research. Similarly, practicing designers say that academic methods are not realistic or accessible for use in real environments. Shorrock and Williams identify accessibility, usability, and contextual constraints as significant barriers that affect the application of theoretical methods in practice. The critique involves a lack of user focus; applicability to real, complex environments; useable data; time; cost; and practical outcome. They also critique the testing of methods. Although HF includes hundreds of methods, few of them have been tested for reliability and for the validity of the outcome (Shorrock & Williams, 2016).

If we accept this critique of methods in HF, then this discipline shares an important gap with the domain of interaction design. This gap affects not only development and the use of methods, but also the final design outcomes. However, in HF, system design and operator behaviour can be separated in two different fields. The first is the design of information displays and control panels, termed human–machine interaction (HMI). The second, situation awareness (SA), refers to the cognitive processes of an operators' perception and comprehension of the situation, along with their projection of what might happen.

HMI and SA both overlap in several areas with interaction design practice. These intersections are important for the objective of this thesis. The following section first describes HMI in relation to HF and the design of safety-critical systems. SA is later described in section 2.3.6.

2.3.3 HF and Human–computer interaction

To better understand the role of HF and HMI in the design of safety-critical systems, one can look at the neighbouring research field, human–computer interaction (HCI). According to Fallman (2008), this field also overlaps with interaction design research.

HCI is situated among computer science, behavioural science, design, and media and focuses on observing the ways humans interact with computers. It also examines the design technologies that allow expected interaction between humans and computers (Card, Newell, & Moran, 1983). Since HCI is a multidisciplinary field, researchers from different backgrounds have contributed to its development. HCI also refers HMI to as man–machine interaction (MMI), and computer–human interaction (CHI) (Carroll, 2015). A consequence of HCI's multidisciplinary nature is that the difference between HF and HCI can be perceived as unclear. This difference has been debated for years in various forums and blogs. According to Carroll (1997), the founder of the human–computer interaction study, HCI is adjacent to HF, and they overlap when addressing interactive systems and contexts. However, he states that HF has 'regularly exerted greater problem-solving discretion' (Carroll, 2015, sec. 2.1). The field of HF encourages more care and prudence in uncovering user needs and identifying the tasks that require attention and action.

The overlap between HF and HCI is particularly interesting in relation to the topic of interaction design research addressed in this thesis. This overlap can provide valuable, complementary insights that may support the transition of design practice into the domain of safety-critical systems. However, there are certain obstacles to the craft of conceptualising HMI designs that are appropriate for an operator´s tasks and workflows.

2.3.4 Translation of analysis to HMI

In *Introduction to Human Factors Engineering*, Wickens et al. (1998) argue that it is ineffective to focus solely on interface design, something they call 'painting the corpse.' This means that HMI design must address the analysis of a particular commission, which includes following standardised guidelines and methods. However, I suggest that this argument can be seen as a contradiction, since the majority of the literature in this field focuses on system architecture, system redundancy, and software development and testing (Bowen & Stavridou, 1993; Cohill, 1989; Knight, 2002).

Over the last three decades, HF has been critiqued for providing few guidelines for HMI design, and those few are outdated (Dumas & Salzman, 2006; Ives, 1982; Tufte & Graves-Morris, 1983). Although this has been the case for some time, little has been done to address it. Lintern (2013) points out that HF and HCI have not done a good job of connecting established theory to analysis, nor have they followed through with strong concepts that link analysis to design.

Related to the design community, the academic field of computer-supported cooperative work (CSCW) has made attempts to utilise theory from ethnography as basis for design, technology and organisation. An example here is the work of Heath and Luff (1992) in the design of London Underground Line control rooms. In this case, the focus is on collaboration and tacit work practices in the control room, not so much design of HMI.

A branch of HF that has attempted to link theory to design of HMI is ecological interface design theory (EID). EID starts with analysing the environment. This analysis identifies the environment's functional purposes, abstract function, general function, physical function, and, finally, physical form. These become data sets and models that are claimed to support higher cognitive processes, such as problem solving and decision-making (Vicente, 2002). However, Vicente admits that the choice and implementation of form in the final design is an obstacle in this model. He suggests that this process is more of an art than a science. Vicente also says that a great deal of creativity is needed to visually translate the data models into the form of the interface. This task, he suggests, is more suited to designers than engineers.

Lintern's and Vicente's work identify important gaps in HF that are relevant to this thesis. Vicente's reflections are of particular interest. However, I have not found any other work on this topic. I attempted to track down Vicente and learned from his protégé, Professor Greg Jamieson, that Vicente became seriously ill and had to stop his work on the gap between engineering and design. Professor Jamieson is not aware of any other research addressing this gap. Nevertheless, Vicente´s reflection presents an interesting topic for this thesis, since it sheds light on a potential complementary role for design practitioners in the design of safety-critical systems.

2.3.5 Connecting to established theory

Again, Lintern (2013) argues that HF fail to connect theory to analysis and analysis to design. However, translating an analysis into a conceptual design requires an established theoretical framework. This is an important component of this thesis, since most design practitioners have not been trained in the theoretical frameworks of HF. This section describes a theory that can support design practice in translating analysis to concept design.

HF examines the overall cognitive process of decision-making. However, there is an ongoing debate about fundamental assumptions concerning decision-making in HF (Flach, 2015). Three theoretical frameworks are at the centre of this debate: sensemaking (Weick, 1995), naturalistic decision-making (NDM) (Klein, 1993), and situation awareness (Endsley, 1995). The debate has recently been criticised by Flach (2015) for being a 'fog of war' with a lot of confusion and little significance. Since these discussions have few implications for my research, this debate will not be addressed here. However, an overview of the debate is provided in a special issue of the *Journal of Cognitive Engineering and Decision Making* on situation awareness (Pritchett, 2015). I will highlight the practical values and applications of the situation awareness framework here. Central aspects of situation awareness are qualities such as ability to communicate across disciplines and a user-centred focus; these are important for design practitioners employed in an unfamiliar domain. As Byrne explains, 'Situation awareness is an intuitive and intrinsically satisfying construct that is applicable to both understanding and enhancing human performance in applied environments' (2015, p. 85).

For these reasons, this thesis will use SA as a framework for connecting theory to analysis in the design of safety-critical systems.

2.3.6 Situation awareness framework

The theory of situation awareness (SA) has become widely used in HF over the last 25 years. Although widely debated, the model is considered the most extensive and most-frequently referenced theoretical framework in work on safety-critical systems (Golightly, Wilson, Lowe, & Sharples, 2010). Over the last 25 years, SA has been used to develop information displays, automated systems, and even training approaches for improving operators' SA (Endsley, 2015). Initially developed in aviation, SA has applications in many safety-critical fields, such as air traffic control, transportation, medical systems, and maritime operations.

This thesis will generally use the original Endsley 1995 SA model (Endsley, 2011). This model defines SA as 'the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future' (Endsley, 1995, p. 36). Or, as Endsley later summarises: 'Basically, SA is being aware of what is happening around you and understanding what that information means to you now and in the future' (2011, p. 13). In this model (Figure 12), SA has three levels that lead up to a decision:

1. Level 1 – *perception* of the elements in the environment
2. Level 2 – *comprehension* of the current situation
3. Level 3 – *projection* of future status

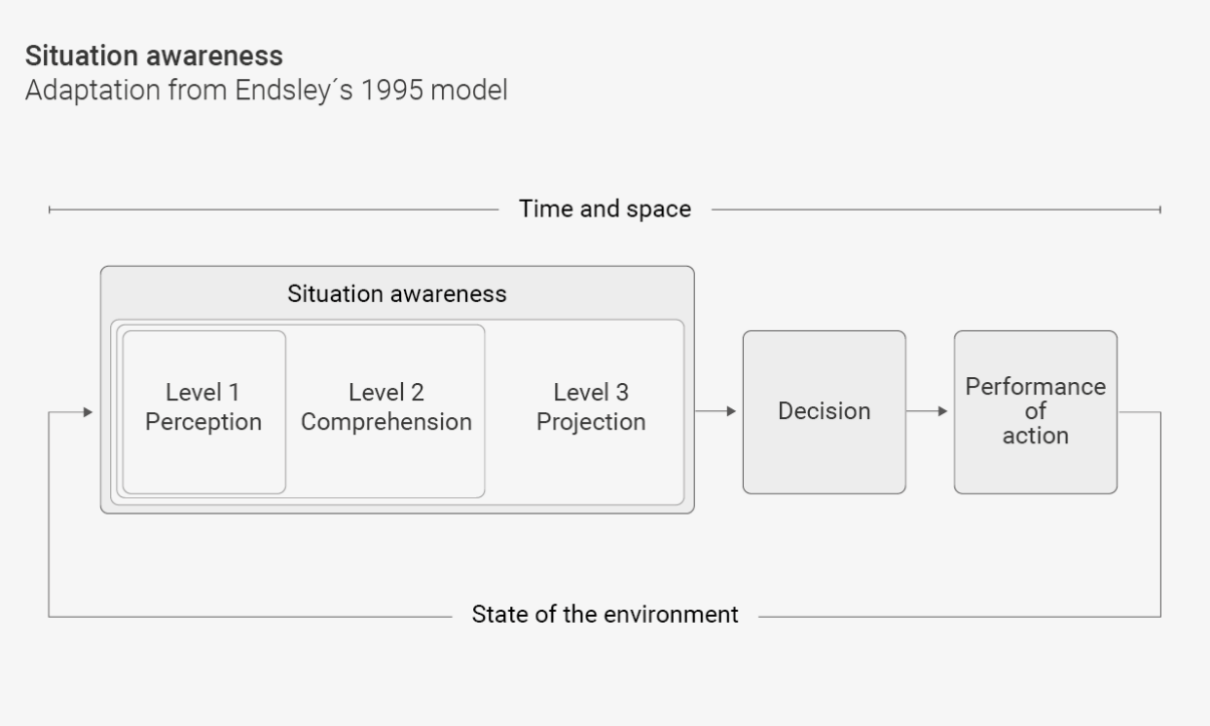

Figure 12. Endsley´s 1995 model of SA. Figure adapted by the author.

In HMI design, the goal at all three levels is for an operator to achieve SA in a timely fashion. According to Endsley, this occurs in the mind of the operator (Wickens et al., 1998). Similarly, Narderpour, Lu, and Zhang (2014) describe SA as a measure that aims to support an operator's ability to handle abnormal situations. From a cognitive perspective, SA can reduce workload, stress, and error rates. These are important factors and illustrate the value of SA in HMI development. Jones (2015) argues that SA allows designers to focus on identifying the type of information that is needed to support an operator. This information is then used to guide and evaluate the design process to create a system that focuses on the user (Jones, 2015).

As previously described, SA has been extensively debated and researched over the last two decades. The debates range from practical applications to differing interpretations of the model. Dekker and Hollnagel (2003) critiqued SA theory as a 'folk model' that lacks detail and a scientific basis. Parasuraman, Sheridan and Wickens (2008) then discredited that argument with a strong collection of empirical research. This research demonstrates the direct usefulness of SA and its theoretical and empirical distinction from performance. An overview of these arguments is presented in Endsley´s recent paper 'Misconceptions and Misunderstandings' (Endsley, 2015).

In this thesis, the theory of SA provides valuable knowledge and an understanding of human behaviour and capacities. However, in my literature review, I found few or no practical methods that translate analysis to conceptual designs. Although goal-directed task analysis (GDTA) can provide valuable guidance, it is geared towards information retrieval, not the conceptualisation and generation of interaction designs. Here I would presume that concepts found in design, such as designerly ways (Cross, 2006) and the ultimate particular (Stolterman, 2008), has the potential to complement and enrich HF theories, such as SA and

GDTA. In this manner, overlapping the two disciplines presented in this thesis can contribute to expand the understanding of how safety-critical systems can be designed.

2.3.7 Summary of design and HF

The previous section introduced and positioned this thesis in the area of professional interaction design practice employed in the unfamiliar domain of safety-critical systems. The literature shows that most research-developed methods of professional interaction design lack applicability to and resonance with the real-world constraints found in everyday design practice. As a result, designers pragmatically develop and adapt their own design methods to fit the situation at hand. Little research has been done in the new, emerging field of design practice in the context of safety-critical systems. However, recent studies show that challenges occur when design proposals are presented in this context due to the designer's lack of domain specific knowledge and HF theories. On the other hand, HF research equally illustrates that HF has not succeeded in translating analysis to conceptual designs that are connected to fundamental theory. Furthermore, HF methods have recently been critiqued for a lack of user focus and for inapplicability to real environments.

The overlaps between interaction design practice and HF point to important gaps in the early phases of product development. These gaps are important for two reasons. First, they can further clarify the position of this thesis. Second, these gaps may – in extreme cases – result in loss of life or damage to the environment or the economy. However, in order to define the gaps in the context of research, I will first establish a philosophical foundation for this thesis to further clarify the nature of real-world practice.

2.4 A philosophical perspective

The following section first outlines key philosophical perspectives in design. Then it introduces pragmatism as an imported world view and demonstrates its resonance with the context of this research.

2.4.1 Philosophical perspectives in design

In discussing criteria for approaches and methods in design research, Friedman (2001) suggests that philosophy and design theory should be linked so designers can inquire and reflect and then build better artefacts with better understanding. Similarly, Rogers (2005) proposes 'importing' theoretical positions to inform the research and development of interaction design discourses. On the other hand, in the book *Interpreting Qualitative Data*, Silverman (2006) argues that it is not necessary to define and understand the terms of philosophical positions to conduct good qualitative research; 'Indeed, if you try to understand them, my guess is that you will not emerge from the library for many years' (Silverman, 2006, p. 7).

Although I think Silverman has a point, it was important for me to understand the big picture of my research. So, if I follow the advice offered by Friedman and Rogers, the imported philosophical and theoretical position should resonate with the context of my industrial PhD project. However, different philosophies highlight different aspects of knowledge. For instance, Brinkmann and Kvale (2014) identify phenomenology, hermeneutics, and pragmatism as three philosophies that are appropriate to qualitative research but provide

different contexts and aspects of knowledge production. To avoid falling down Silverman´s philosophical rabbit hole, I will now present a short outline of these three world views.

The central focus of hermeneutics is the study and interpretation of text. The purpose of the interpretation is to obtain a valid, common understanding and identify the meaning of the text (Brinkmann & Kvale, 2014). Hermeneutics has roots in German philosophy, and philosopher Hans-Georg Gadamer (1900-2002) became the authoritative figure in hermeneutics with his contribution *Truth and Method* (Gadamer, 2004). Lately, the concept of 'text' has been extended to include discourse and, to some extent, action. This means that a hermeneutical approach involves making explicit a practical understanding of human actions through interpretations that make sense in one's research (Gray & Malins, 2004). In design research, Friedman (2003) describes hermeneutics as a research method that allows for multiple interpretations of a text, giving each researcher his or her own voice.

In phenomenology, the core goal is to describe the given as precisely and completely as possible. This means describing a situation rather than explaining or analysing it (Brinkmann & Kvale, 2014). Phenomenology was founded by Edmund Husserl (1859-1938) and further developed by Martin Heidegger (1889-1976), Jean-Paul Sartre (1905-1980) and Maurice Merleau-Ponty (1908-1961) into a philosophy that includes human life and action in the world and in a historic context. According to Creswell (2013), in research, phenomenology is an approach in which the researcher describes the lived experiences of individuals in order to describe a phenomenon that was experienced by several individuals. It is a type of inquiry that typically involves conducting interviews and has strong philosophical underpinnings (Creswell, 2013). Notably, in interaction design, phenomenology has been employed to discuss social issues such as social perceptions of embodied technology (Dourish, 2004) and artificial intelligence (Gallagher & Zahavi, 2012).

As described above, one philosophy that is repeatedly referenced in design practice research is pragmatism. Authoritative scholars such as Buchanan (1992), Schön (1983), Cross (2006), and Stolterman (2008) name pragmatism as an influence on discussions and approaches in practice research, design, and situations where design is used. Pragmatism can be seen as an umbrella term for a philosophical movement established in the 19th century by American philosophers such as Charles Sanders Peirce (1839-1914), William James (1842-1910), and later on, John Dewey (1859-1952). Dewey is probably the most well-known of these philosophers and addressed a number of issues (such as education, psychology, logic, experience, and art) using his philosophical principles (Dalsgaard, 2014). As mentioned before, the central assumption of pragmatism is that actions, situations, consequences, and knowledge do not copy reality but are means of coping with a changing world. This means that thought is an instrument or tool for making predictions, solving problems, and taking action, and success is measured by practical application (James, 1997). As Creswell (2013) points out, truth is what works at the time to produce the desired result.

Of these three philosophies, pragmatism was identified as the most appropriate one to import for this research. Two primary factors support this position. First, prominent scholars like Schön, Buchanan, and Cross have connected pragmatism with practice-based design. The second factor was my reflections on the resonance of this literature with my personal experience and the potential relevance of each philosophy to my industrial PhD.

2.4.2 Design and pragmatism

As mentioned in the previous section, pragmatism is useful for developing practical approaches, providing understanding of situations and for obtaining valid knowledge in practice-based design. Researcher and design practitioner Kumar states, 'Pragmatism governs thinking about the practicality of making ideas real and devising the reliable tactics to make that happen' (2012, p. 286). Dalsgaard (2014) has recently published an excellent paper that offers an extensive explanation of and argument for the connection between design thinking and pragmatism. Dalsgaard argues that pragmatism offers a well-developed, comprehensible framework that is central to theoretical and practical concerns in design thinking. On the theoretical side, pragmatism can inform and inspire the development of design discourses. On a practical level, pragmatism can be operationalised to inform and guide design projects, as well as to help designers understand and organise design processes (Dalsgaard, 2014).

Although pragmatism is often considered as one school of thought, interpretations of Peirce and Dewey and of their conceptualisations of inquiry are not completely consistent (Talisse, 2002). Since these inconsistencies have minimal implications for my research, I will not discuss these different perspectives here, but Shalin (1986) and Talisse (2002) provide detailed accounts of them. However, on this topic, I will say that Deweyan concepts in pragmatism are particularly relevant to managing and explaining design practice. For this reason, my thesis will generally draw on selected Deweyan concepts such as situation, inquiry, transformation, and experience.

2.4.3 Primacy of practice principle

Most modern readers find Dewey´s style of writing dense and complex (Dalsgaard, 2009). Even in his own time, Dewey's works were perceived as intricate and poorly written (Fisch, 1995). Since I am not a philosopher or a linguist, I will draw on contemporary rearticulations and interpretations of Dewey´s work. These interpretations may or may not be accurate according to pragmatist scholars. However, my goal in employing Deweyan concepts is to reflect on and understand my research, not to dwell on particular articulations of his ideas.

The primacy of practice principle is at the core of pragmatism. First conceived by Peirce as the pragmatic maxim, the principle assumes that all human activity is situated and that neither the subject or phenomena can be understood outside of the situation. This means that human actions and thoughts, as well as objects and events, must always be understood in the larger context of a situation (Dalsgaard, 2014). According to Dewey, a situation is not defined by a single object, event, or events, because one never experiences or forms judgments about objects and events in isolation, only in connection with a contextual whole. This contextual whole is a situation (Hickman & Alexander, 2009). The nature of a situation can be dynamic, since the world (according to pragmatism) is inherently changeable, and these changes constantly create unfamiliar situations. According to Dewey, we may experience unfamiliar situations as problematic and seek to transform them into predictable situations through inquiry (Hickman & Alexander, 2009).

According to Dewey, inquiry is the shared process of reflection and action we undertake when trying to frame the boundaries and parameters of an unknown situation. The situation may appear problematic because our experience and habitual responses do not result in the

expected outcome (Hickman & Alexander, 2009). The process of inquiry can be seen as a series of events. In the first, we recognise the situation and then conduct simultaneous thoughts experiments. The results of these experiments are used to hypothesise how to transform the situation and evaluate which actions may best resolve it. In such a transformation, the components of the situation shift and change until a unified whole is achieved. This is done before we act in the world to find out if the hypothesised action will have the desired outcome (Dalsgaard, Dindler, & Eriksson, 2008; Hickman & Alexander, 2009). In this context, the primacy of practice principle states that theories are formed in relation to specific situations; consequently, in practice, experience takes precedence over doctrines (Dalsgaard, 2014).

2.4.4 Pragmatic validity

The notion of achieving a desired outcome is often linked with the term 'pragmatic validity.' As mentioned in the introduction to this section, truth is whatever lets us take action that produces the desired result (Creswell, 2013). Founded on Dewey´s concern that traditional epistemology was overly occupied with the logic of proof and results, pragmatic validity attempts to overcome the conflict between theory and action (Bernstein, 1971). In pragmatic validity, knowledge can be judged by the degree to which goals or intended outcomes can be achieved by performing certain actions or employing particular instruments (Rescher, 1977).

A recurring theme in this thesis is the gap between real-world problems and theoretical approaches. Worren et al. (2002) state that there is little consensus on how pragmatic valid knowledge is created. Therefore, Worren et al. (2002) introduce a framework for pragmatic validity consisting of three perspectives: propositional, narrative, and visual. They then highlight the role of the visual format in achieving validity through the symbolic representation of concepts and relationships and by simplifying complex information into meaningful patterns. Such visual representations can be used to guide actions and reach goals, thus achieving validity. However, Worren et al. (2002) also stress the possibility of inherent bias in direct user feedback and self-assessments of validity. On the other hand, Brinkmann and Kvale (2014) argue that pragmatic validity rests on observations and interpretations that include a commitment to act on those interpretations. According to Brinkmann and Kvale (2014), in the validation of knowledge, knowledge is demonstrated through an action's effectiveness.

2.4.5 Summary

This section provided overviews of phenomenology and hermeneutics and introduced pragmatism as the imported world view in this research. Although the other worldviews described also hold potential for design research, pragmatism grew out of actions, situations, and consequences, rather than pre-existing conditions (Creswell, 2013). This means that, in pragmatism, the main focus is on the research problem and on using applications *that work* to derive knowledge and achieve a solution (Hickman & Alexander, 2009).

Over the last three decades, numerous influential scholars and practitioners have employed pragmatism to understand and manage practice-based design research (Buchanan, 1992; Cross, 2006; Kumar, 2012; Schön, 1983; Stolterman, 2008). As a result, many existing well-

developed theories offer a rich body of work for me to draw on, from intricate accounts of Dewey's ideas to Schön´s and Buchanan´s theories on design practice and practitioners in real-world situations. This literature has been instrumental in providing an explicit description of my research context. In particular, the primacy of practice principle provided me with one of my most significant personal insights in this study and helped transform my tacit knowledge of design practice into an explicit, articulated understanding in my research.

3 PROBLEM STATEMENT AND RESEARCH QUESTIONS

This section outlines and positions three gaps in the existing research and then presents my research aim and the research questions addressed in this thesis.

3.1 Problem definition

I have identified three primary gaps in the existing literature in the fields of interaction design and HF. The gaps are particularly obvious from the perspective of interaction design, but they are equally present in the field of HF. Since this thesis is an industrial PhD, I used Halogen´s design process to illustrate the position of the gaps in the existing body of research (Figure 13). Halogen employs a human-centred design process (ISO 9241-210, 2010) and is inspired by the processes of the design company IDEO (IDEO.org, 2015). Halogen's design process has three main phases: insights, concepts, and design. The three gaps addressed in this thesis are located between the insights and concepts phases. The next section outlines these the three gaps in the context of this research.

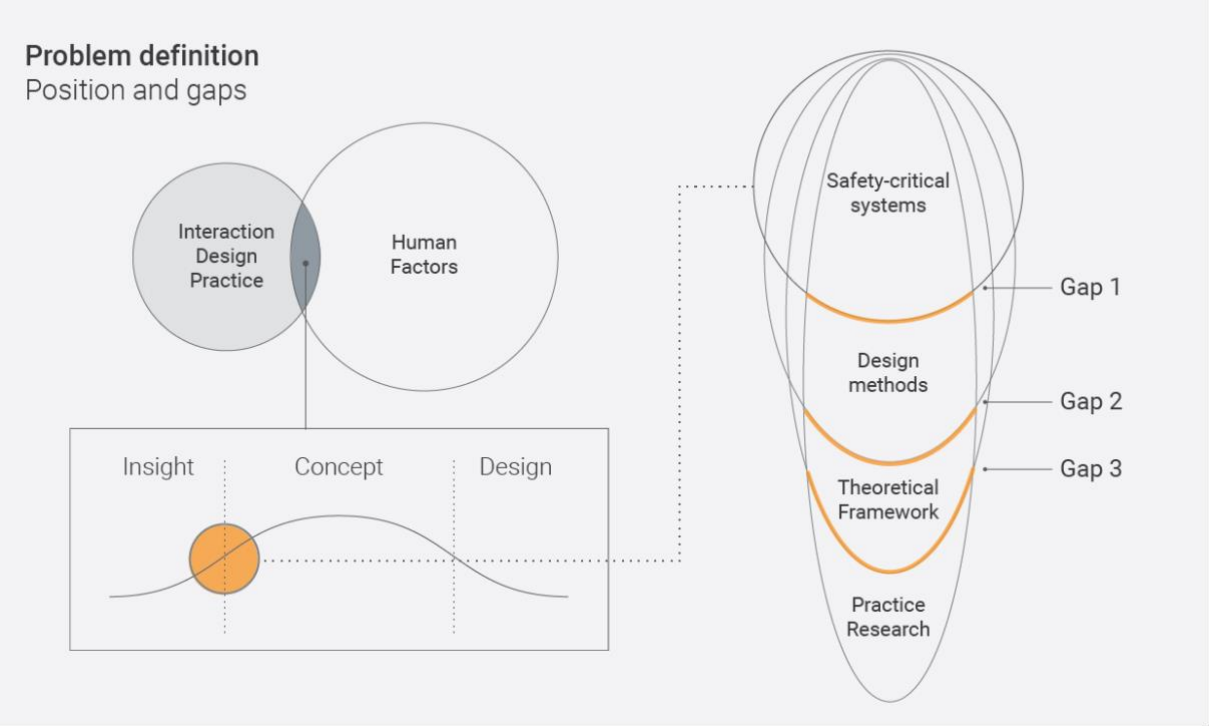

Figure 13. Existing research and the position of three gaps.

3.1.1 Gap 1 – The lack of safety-critical design methods

The first gap concerns the lack of formalised design methods for design practitioners who design safety-critical systems. This is a problem particularly due to the lack of relevant, applicable design methods for interaction design practice (Gray, 2016). Most notably, there is a lack of design methods that can support multidisciplinary design judgment and argumentation early in the design process. Current research does address the lack of vocabulary for and understanding of unfamiliar HF theories and principles among design practitioners. To quote Lurås´s once more: 'To say "I just feel this is right" does not hold in these industries' (Lurås et al., 2015, p. 146). This statement addresses designers' lack of

vocabulary and also the resistance to designerly ways of doing and knowing in an unfamiliar domain with long scientific traditions.

A second dimension to this gap can be observed from an HF perspective. Although HF has established a theoretical framework, it lacks practical methods and approaches to translate analysis into strong conceptualisations (Vicente, 2002). Lintern (2013) discusses the need to connect concepts to analysis and analysis to fundamental theory. However, this is not a straightforward process. The practical application of HF methods has been criticised as overly complicated and time consuming, as well as for a lack of user focus in applied environments and a failure to provide relevant knowledge claims (Shorrock & Williams, 2016). Thus, it is reasonable to say that design practitioners and HF practitioners lack the same two main components of a method: first, applicability in real-world constraints in applied environments, and second, the ability to support informed judgments and arguments early in the design process.

To explain this gap in broader terms, I would say that the literature on HF and on design lacks practice-based frameworks to develop methods for safety-critical systems. This presents an everyday problem for practitioners employed to design safe, robust solutions. This is particularly problematic for interaction design practitioners, which lies outside the scope of HF and in which the potential consequences of poor design are severe.

3.1.2 Gap 2 – The lack of current understanding

The second gap concerns the lack of knowledge of how design practitioners use design methods in the context of safety-critical systems. Although research shows that design practitioners pragmatically use and adapt design methods to fit a given situation (Goodman et al., 2011; Gray, 2016; Rogers, 2005), this research does not explain the use of such methods in the context of high-risk applied environments.

This lack of knowledge is problematic, since safety-critical systems have traditionally been seen as outside the design discipline (and have not employed designers). As Lurås et al. (2015) comment, this is a relatively new domain for both the industry and the design profession. So, it is reasonable to say that this is an unfamiliar, emerging field of design research. Consequently, little or no in-situ research has been done on design practitioners and their use of methods in this particular real-world context. Thus, it is natural to suggest that design research has not yet had the time or the framework to develop specific design methods for safety-critical systems.

I would argue that this lack of knowledge about how methods are currently used in practice represents a significant problem for future method development. This gap does not only affect design research; it affects design practitioners' own awareness and understanding of method application in a high-risk domain.

3.1.3 Gap 3 – The disconnect between practitioners and researchers

The third gap addresses the overall lack of a relationship between practitioners and researchers concerned with method development. Over the last decades, the relationship between research and practice has been widely researched and discussed by prominent scholars such as Cross (2006), Durling (2009), Friedman (2000), and Schön (1983). Within this

discourse, some researchers have focused on method development (Dickson & Stolterman, 2016; Hanington, 2003; Rogers, 2005; Stolterman & Pierce, 2012). Although this discourse has had some useful effects, recent studies show that there are still misunderstandings and a lack of shared knowledge between the research and practice communities (Gray, 2016).

This disconnect can be problematic for several reasons. It suggests that, in many cases, researchers invest resources in developing methods that are then largely ignored by practitioners. At the same time, professional designers view research-developed methods as out of touch with the reality of real-world design. As a result, design practitioners do not see the potential value of research (Gray et al., 2014). Researchers regard this gap as a consequence of an academic conception of practice due to a lack of in-situ, empirical descriptions of designers´ actual work (Dickson & Stolterman, 2016; Goodman et al., 2011; Gray, 2016).

A similar gap, called the research–practice divide, exists between HF researchers and practitioners. A primary concern is that research methods developed in academic institutions are difficult to access and use in applied environments. Since new methods are often irrelevant in practice, academics worry that practitioners mostly rely on old methods, and new, improved methods are rarely adopted (Shorrock & Williams, 2016).

Overall, there seems to be a lack of understanding of how the relationship between research and practice can be improved. Furthermore, the lack of a practical, shared space between research and practice seems to be a consistent gap in all the areas addressed in this thesis. This gap may be the root of the problems in the first and second gap.

The next section describes the aims of this research and questions employed to examine the identified gaps.

3.2 Research aim and questions

My research aim and questions are influenced by the industrial context of this PhD and by my motivation to support fellow researchers and practitioners employed in designing safety-critical systems. Since design practice in safety-critical systems is an emerging field, the research questions aim at a qualitative understanding of the real-world to guide the research and explore a particular approach to gaining new knowledge (Luck, 2014). This particular approach uses a pragmatic strategy to meet the changing, unpredictable situations found in professional design practice.

The overall aim of this thesis is to *investigate, in-situ, how design methods can be improved in the context of safety-critical systems.* In order to pursue the aim, three questions will be addressed:

1. How can professional designers' use of design methods be explained?
2. How can design methods be developed to support practice?
3. How can design methods be consistently evaluated in practice?

These questions are not autonomous; they exist in relation to each other (White, 2011). In line with pragmatic inquiry, the questions are designed to reveal the contextual whole rather than single events or objects (Hickman & Alexander, 2009). With this in mind, these

questions are designed to support inquiry and an understanding of the processes, methods, and operations in the gaps described above.

To address gap 1, a fourth research question was posed: *How can an unfamiliar theory systematically support the translation of analysis into concept designs for safety-critical systems?* However, because of the specific project that forms the basis for this industrial PhD, the findings of this research are proprietary. Thus, the answers to this fourth question are presented separately from the academic contributions of this thesis.

To address the aim and the research questions, this research process focused on two primary goals:

- To build on existing knowledge and offer a better understanding of tools and methods that are relevant to practical interaction design research
- To develop methods and tools that may support interaction design practitioners in the design of safety-critical systems

This study has drawn on recent developments in interaction design research to position this research process as a part of everyday professional design practice. The following chapter describes the research approach and the methods used in this study. These methods pragmatically enabled in-situ designing as well as the use and evaluation of design methods in commissioned projects.

4 MAIN RESEARCH APPROACH AND METHODS

This chapter outlines my qualitative, real-world research approach to the interaction design research triangle and describes main research methods I used in the field setting of a commissioned project in Halogen. It then describes how I tried to reach a higher level of abstraction by going beyond the interaction design research triangle. Finally, the chapter identifies the limitations of this research.

4.1 Qualitative, real-world research

The research approach in this thesis is primarily qualitative; this study seeks to explore and understand the real-world context of a small group of humans – specifically, the professional design practitioners employed at Halogen. Flick (2009) calls a particular object like this an institution. However, since 'institution' has a different meaning in design literature, this thesis will use the term 'practice' instead of 'institution.' This kind of research is difficult to control in advance due to the participants' everyday time constraints and other obligations. It may be problematic to secure participants' collaboration, or they may be unwilling to express opinions or provide access to data. In this thesis, the field of study is not an artificial laboratory situation but the professional practice of everyday life. Consequently, this kind of study is suited to qualitative research (Flick, 2009).

In the context of this industrial PhD, the qualitative approach in a practice can be further framed as real-world research. This term is used for applied research projects that are usually small in scale and modest in scope (Robson, 2011). Real-world research considers systems, initiatives, and participants' personal experience and social lives. The goal of real-world research is to understand the lived reality of people in society and the consequences of that reality. Robson (2011) suggests that real-world research can shape the world as well as explain the status quo. Thus, the focus is different from academic research, which is designed to develop and expand an academic discipline.

Because I am an industrial PhD fellow, my approach will not maintain Robson´s distinction between real-world and academic research. Although my research takes place in a real-world context, I will also seek to contribute to academic knowledge of my topic. Thus, the aim of this research is twofold: to obtain results that improve Halogen as a practice, and to learn how research in practice can be conducted. As an effect of this learning process, I aim to expand on the existing design literature with knowledge gained from researching design practice.

4.2 Researching design practice

In the paper 'Understanding Interaction Design Practices,' Goodman et al. (2011) warn that studying a practice, especially a professional practice, is not a straightforward endeavour. They believe that interaction design, a new form of professional practice, needs a diverse set of complementary, explorative research methods to deal with its complexity and promote a better overall understanding of the field. Gaver (2012) argues that, instead of worrying about a scientific ideal, the design research community should reflect on appropriate ways to pursue design research on its own terms. Motivated by Gaver and Goodman, I have drawn on my own 12 years of practice experience years to explore and expand on established design and HCI research methods.

4.3 Design research models

There are a number of models for qualitative research in a practice-based design context. These models also use various definitions that aim to position and explain the research approach. Cross (1999), classifies different types of design research based on whether they are primarily concerned with obtaining knowledge from people, processes, or products. Cross's three categories are: (1) design epistemology, the study of designerly ways of knowing; (2) design praxeology, the study of the practices and processes of design; and (3) design phenomenology, the study of form and of the configurations of artefacts. Other models acknowledge that design research is being both an intellectual and an applied discipline. Related to this, Friedman (2000) suggests four areas that design research needs to address. These are: (1) the philosophy and theory of design, (2) research methods and research practices, (3) design education, and (4) design practice. One of academia's most prominent and enduring design research methodologies is Frayling´s (1993), which categorises design research into 'research into design,' 'research for design,' and 'research through design.' This model can be used to identify different roles and modes of inquiry in design research (Pullin, 2014). Notably, Zimmerman et al. (2007) draw on Frayling and suggest a model for 'research through design' in interaction design research within the field of HCI research. This model allows researchers to engage with wicked problems that cannot be easily addressed through traditional scientific approaches.

Each of these models presents different challenges for researchers, and each requires different skillsets and approaches and results in different types of knowledge. Fallman (2008) compared various models of design research and observed that researchers and practitioners often find it confusing to choose an appropriate approach to interaction design research. He argues that this confusion could result from the abundance of disciplinary groups involved in design research, all of which have their own theoretical foundations. Similarly, Stappers and Giaccardi (2013) state that, in the late 2010s, theories on research through design were still in the developmental stage. They suggest that this can be observed in communities that struggle to find the right words, models, and practices. As a PhD candidate, I have also observed such confusion in the PhD research community on several occasions. This confusion showed me the communicative and practical capabilities of various research models. I regard this as an important aspect of my research, since I need to communicate my findings to practitioners and industrial partners outside the academic community.

To address this disciplinary confusion, Fallman (2008) developed the interaction design research triangle of design, which combines design practice, design studies, and design exploration in one model. Although inspired by Frayling (1993), Fallman (2008) argues that the combination of the three perspectives distinguishes interaction design research from other related disciplines, such as Human-Computer Interaction (HCI), Computer-Supported Collaborative Work (CSCW), industrial design, and computer science. Fallman´s model, also known as the Triangle, has become known for influencing methodological innovations in practice-based design doctorates (Yee, 2010). The paper introducing the Triangle is the fifth most downloaded article from *Design Issues* from 2001 to 2014 (Pullin, 2014).

In the light of the Triangle´s influence and practical application, I found the Triangle to resonate with my research topic. The following section will present the model and how it was employed in my research.

4.4 The interaction design research triangle

In its most basic form, the model is a two-dimensional triangle that shows three extremes: *design practice*, *design studies*, and *design exploration* (Figure 14). These activity areas can be used to plot the position of research activities. Pullin (2014) points out that the activity areas can generate both generic and specific knowledge. Outside the triangle, the three activity areas represent the different perspectives of industry, academia, and society at large. Pullin (2014) finds this aspect of the model particularly interesting because it has the potential to interact with individuals and disciplines outside the context of design research. I propose that this is an important argument that resonates in my research context, which involves multiple individuals and interests positioned both inside and outside the research triangle.

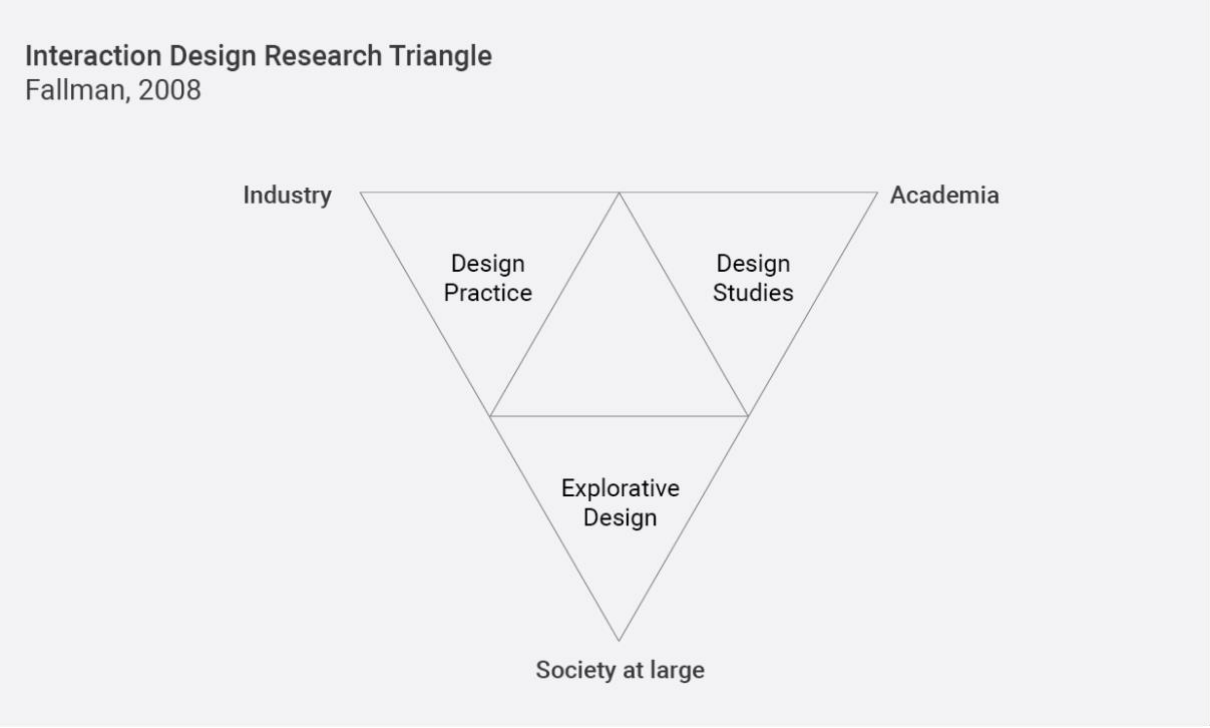

Figure 14. The most basic form of the interaction design research triangle. Figure redrawn by the author.

The internal space of the triangle consists of three activity areas, each of which represents a certain disciplinary perspective.

Design studies is the activity area that most closely resembles traditional academic disciplines. It is also where influences from other disciplines are most prominent (Fallman, 2008). In design studies, the overall goal is to help build and extend knowledge about design theory, design methodology, design history, and design philosophy. This typically involves rigorous analytical work and discursive activities in publications, gatherings, and conferences. However, Fallman and Stolterman (2010), argue that, in design studies, rigour does not necessarily require complex statistical methods and controlled experiments.

Rather, in this area, rigour is determined by a design researcher's ability to put forward and support a claim using a systematic, clear, transparent approach and a coherent chain of arguments that builds on earlier research.

Design exploration is an activity area that often involves testing ideas and asking 'what if?' It is based on theories, ideals, technology, or other alternative foundations for design (Fallman, 2008). It is not commercially driven; projects are typically self-initiated, and the goal is often to question, provoke, criticise, or experiment in order to reveal alternatives to established or expected paradigms. Design methods in this activity area tend to be interpretive and discursive and are often driven by a hypothesis or theory. Overall, design exploration is a type of research that explores new technologies or solutions in order to 'rock the boat' rather than seeking to solve existing, well-defined problems (Fallman & Stolterman, 2010).

As their names imply, the areas of *studies* and *exploration* have primarily an academic, experimental nature. Thus, they do not immediately fit my particular field of study. Design practice, on the other hand, is an activity area that resonates with my real-world research in Halogen. In design practice, the actions of interaction design researchers are similar or identical to those of design practitioners (Fallman, 2008). This could include working for a commercial design organisation, in an in-house design department, or developing client commissions for a design consultancy. Fallman and Stolterman (2010) argue that interaction design researchers should be, first and foremost, involved as proactive designers in a design team. They should not be observers who do not personally participate in design. The reason for this is that this activity area involves accessing the tacit competence and knowledge that are used during a real-world design process (Fallman & Stolterman, 2010).

In many ways, the characteristics of *research through design* (Frayling, 1993) and *design praxeology* (Cross, 1999) are visible in this activity area. Design praxeology is the study of design practice and processes, and research through design implies the use of design as a model for exploring a subject and creating new knowledge (Sevaldson, 2010). In research through design, iterative and explorative modes of inquiry through designerly practice and reflection are valid research strategies (Dalsgaard, 2010). Since, by definition, research as design is closely related to real-world research in practice, I found it appropriate to position my research in this activity area.

4.5 Research as design practice

As a practicing designer and researcher at Halogen, I have been closely involved in commercial design projects. Fallman and Stolterman (2010) explain that this form of research is strongly shaped by the real-world, practical concerns of developing a design in a particular setting for a particular client with a particular purpose. This approach can also be described as first-person research: The designer is reflexively situated as both the primary researcher and the designing individual (Goodman et al., 2011; Sevaldson, 2010). Sevaldson (2010) argues that a first-person perspective gives researchers access to in-depth, tacit knowledge of a practice as they move between creative action and critical reflection.

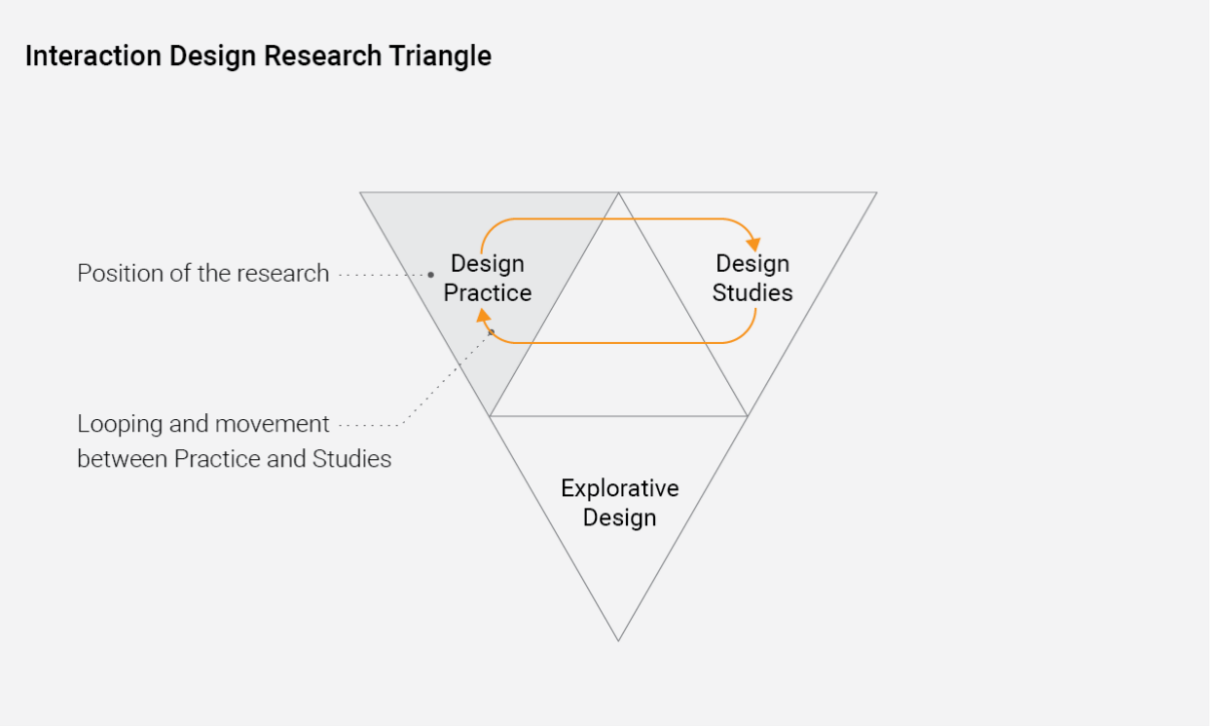

Figure 15. Position of this research and loops in the Triangle.

According to Fallman (2008), the Triangle offers the most rewarding and interesting results when research moves and loops between different positions. Looping between disciplines gives researchers a different perspective on a topic. The perspectives and purposes of the methods and tools used also change as one moves between activity areas. Incorporating multiple perspectives and tools is also something that resonates with the philosophy of pragmatism. Instead of seeing the world as absolutely unified, pragmatism looks for multiple approaches, rather than subscribing to only one (Creswell, 2013). Fallman (2008 argues that, unlike other traditional research models (Cross, 1999; Frayling, 1993; Friedman, 2000), the Triangle enables a researcher to approach inquiry and knowledge construction in alternative ways through free movement and loops. This movement ultimately contributes to rigour and establishes the relevance of the research (Fallman & Stolterman, 2010).

Having the opportunity to systematically move outside my research position enabled me to reflexively loop between design practice and design studies. I consider this movement important to my role as an industrial PhD candidate because it can reduce the confusion of communicating with both practical and scholarly communities.

4.6 Field setting

My research was positioned as a design practice. Fallman (2008) suggests that research activities should take place in some sort of field setting where an interaction design researcher is part of a design team. As previously mentioned, this form of research is strongly influenced by the practical concern of designing the *ultimate particular* (Stolterman, 2008).

When discussing the real-life context of a concept similar to those addressed in this thesis – practice research in action – Sevaldson (2010) points out that, with complete access to inside information, knowledge is generated through immediate action and intervention.

However, he also suggests that the dynamic, complex setting of real-life fieldwork can pose challenges to the generalisation of knowledge. A field setting is the complete opposite of the controlled, artificial setting of a laboratory. The field deals with real-world constraints, including wicked problems, limited resources, client demands and production requirements, all of which affect this environment (Goodman et al., 2011). This means that the methods and techniques for study and creation should contribute to changing the status quo (Fallman & Stolterman, 2010). However, Fallman and Stolterman (2010) also point out that, when the results of research are examined in a field setting, the specific environment must first be clearly understood. Thus, the purpose and constraints of the context should be evaluated in relation to the claims, visible evidence, and relevance of the research.

In an effort to provide this understanding, in the following section, I will describe the main field setting of my research, which was conducted during work on a project for the Norwegian Defence Research Establishment (FFI). Other projects included in this research are control device for unmanned aerial vehicles (UAV), a remote airfield tower concept, integrated operations centre (IOC) for oil and gas for the Norwegian continental shelf, and condition-monitoring systems for remote electrical power grid systems (Figure 16).

Picture is removed in digital version due to commercial interest
Figure 16. Commercial projects included in this research. Top left: UAV controllers. Photo credit: Griff Aviation. Top right: IOC centre. Photo credit: Ola Brandsnes. Bottom: design for a remote airfield tower. Photo credit: Magne Ekerum).

4.6.1 Next-generation submarines

The main field setting of my research was a project commissioned by the Norwegian Defence Research Establishment (FFI). The project was part a larger project to support the Norwegian government in the procurement of new submarines for the Royal Norwegian Navy (FFI, 2017). FFI is responsible for identifying the necessary equipment and technology, and they commissioned Halogen to develop a farsighted but realistic concept design for a submarine operations room. The concept design would primarily serve three purposes: (1) to ensure human-centric design would be used in future operations, (2) to advise the industry about equipment and technology, and (3) to provide input for formalisation and governmental decision-making.

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Figure 17. Operations room of an Ula class submarine. Photo credit: Royal Norwegian Navy.

A submarine is a complex seagoing vessel that has multiple maritime capacities. Its most well-known is the ability to remain submerged and operate independently for a period of time. Depending on the submarine's classification, its crew can range from 20+ on conventional vessels to 80+ on nuclear submarines. These highly trained and motivated operators work and live in close proximity to each other. A new generation of submarines will be phased into the Royal Norwegian Navy starting in the middle of 2020 (FFI, 2017). These new submarines are expected to perform maritime operations for the next 30 years. Incidentally, this means that the majority of future submariners have not even been born yet. This is an example of a central pre-condition that applies to many safety-critical systems that Halogen has designed.

The design object of this project was the operations room, which is positioned in the heart of the submarine (Figure 18). Here, multiple operators work as a team to perform a range of complex tasks, spanning from routine exercises to time-critical and hazardous operations. The FFI project involved developing a complete work and operational environment for submarine operation rooms through interaction design and industrial design. The design solution also needed to facilitate sightlines, workflows, verbal and non-verbal communication between the operators. This required design team to develop a design and operational philosophy to guide the design of the system that is viable for the next three decades.

For in-situ design practice research, this particular field setting represented an interesting opportunity to study *how* designers use design methods and *how* they create designs in relation to *what* they make based on the design object. However, as Goodman et al. (2010) point out, studying professional design practice is not a straightforward endeavour. From my own experience, I find this statement highly apt for describing this particular field setting.

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Figure 18. A designer conducting fieldwork during submarine exercises. Photo credit: Ola Vaagsholm.

4.6.2 Field setting constraints

Aside from the confidentiality requirements, as this project used sensitive client information and data, this particular field setting introduced significant new constraints to the research and development processes (Schønheyder, in review). Due to operational security requirements and the project's confidentiality, this project involved multiple security measures. After background security vetting and authorisation interviews, a design team of five designers worked from a secure project room with restricted access and no access to the internet or other means of electronic communication (Figure 19). Personal computers, cameras, mobile phones, and smart watches were prohibited. Only secure hardware and software provided by FFI could be used. This equipment was not to be removed from the secure room or was carried by each designer at all times at work. The design team (including myself) also travelled several times to conduct field observations of submarine exercises. During these field observations, we lived with and observed submarine crews. The trips lasted several days, during which we had no access to any means of communication or to any electronic devices.

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Figure 19. The designers (including the author) in the secure project room. Photo credit: Bojana Petkov.

This project is classified as confidential by Norwegian law, and, at this point, I am not allowed to reveal specific information or data related to the project. These requirements impose certain constraints on this publication and on my ability to share new knowledge from this study. However, my study's reliability lies in the choice of methodology and in whether the published results can benefit other practitioners without including names or other sensitive data (Archer, 1995).

4.7 Tactics for identifying and selecting methods

Robson (2011) states that a method or methods should be selected based on what kind of information is desired, and from whom and under what conditions the information should be obtained. I identified and selected appropriate research methods for this study based on my goal of finding out *how* a professional design practitioner *uses* design methods in real-world contexts in order to improve practice. I was particularly interested in identifying research methods that could be used to collect data in unfamiliar, high-risk domains.

Again, this was not a straightforward endeavour. The constraints of this particular field setting and of the real-world context of design practice posed certain challenges in selecting appropriate research methods. Robson (2010) argues that any methods that a researcher proposes must fit the constraints of available time and resources. Six additional factors guided my identification and selection of appropriate methods:

- Relevance to the research aim and questions
- Knowledge claim and practical outcomes
- Independent of digital or electronic technologies
- Usability and flexibility in various high-risk environments
- Not dependent on stable research environments
- Applicability to various field settings

This tactic enabled me to pragmatically navigate understanding the various qualities of different methods. For example, protocol analysis, a research method traditionally used to collect and study data about designers' thinking and activities (Cross, Christiaans, & Dorst, 1997), was assessed as impractical due to the unstable, restricted field setting. My assessment of this method is not new; Cross (2004) also suggests that protocol analysis fails to address many of the broader realities of designing in context. He further claims that the method is extremely poor at capturing non-verbal thought processes. However, this was something I particularly hoped to uncover in my own study since our design team operated with restricted communications for long periods of time due to high-risk operations in the submarine.

4.8 Bricolage as a methodological approach

In my search for methods to accommodate the field setting, I drew on Goodman et al.'s (2010) call for explorative, experimental approaches to studying professional practice. This led me to use my experience as a practitioner to iteratively adapt and design my own research strategies and methods to accommodate the field setting. In qualitative research, this particular methodological approach can be described as *bricolage*. Drawing on the work of Levi-Strauss (1966), Denzin and Lincoln (2011) describe bricolage as a qualitative approach in which the researcher becomes a bricoleur, a 'jack of all trades'; this method calls for a kind of professional do-it-yourself. Nelson (1991) explains that if new tools need to be invented or pieced together, a bricoleur will do it. However, this method cannot be defined in advance; it depends on the questions that are asked in a certain context, what is available in the field, and what the researcher can accomplish in that setting (Nelson, 1991). The definition that I personally think appropriately summarises bricolage is provided by Yee and Bremner: 'Bricolage is a useful and necessary concept for design researchers as it allows them to deploy available and established strategies and methods, but also grants them the

license to create new tools and techniques in order to address questions that are beyond the realm of the established discipline' (Yee & Bremner, 2011, p. 3).

The qualitative approach of bricolage uses multiple methods or triangulation in an attempt to secure an in-depth understanding of the topic. The term 'triangulation' was first used in this context by Denzin in 1978. It refers to the application of more than one research strategy to a subject (Denzin, 2006). Since then, it has become a valuable, widely used approach that enhances research rigour (Robson, 2011). Mackay and Fayard (1997), who worked in HCI, state that triangulation reduces the effects of the weaknesses and limitations of individual research strategies. They argue that triangulation in HCI can clarify relationships between disciplines and research paradigms in order to improve validity and value (Mackay & Fayard, 1997).

In such a triangulation process, a bricoleur pieces together the research in a reflexive, interpretive approach. However, Rogers (2012) points out that such a process is never free from subjective positions or political interpretations. On the other hand, Denzin and Lincoln (2011) explain that the bricoleur understands that research is an interactive process shaped by the researcher's personal history. Meanwhile, Flick (2009) proposes that the combination of multiple methodological approaches and data in a single study adds rigour, richness, and depth to an inquiry. Consequently, my approach used open-ended questions, words, and visual reflection rather than quantitative approaches such as closed-ended questions, numbers, and statistical procedures (Creswell, 2013).

In my PhD research, bricolage was warranted by the constraints of my field setting. This led to a pragmatic approach that entailed adopting established research methods and redesigning them to fit the situation at hand. The main research methods that I employed as a starting point were:

- Literature review (Luck, 2014)
- Qualitative, semi-structured interviews (Brinkmann & Kvale, 2014)
- Participatory observations (Denscombe, 2007)
- Prototyping (Houde & Hill, 1997)
- Triangulation (Denzin, 2006)

Detailed accounts of how these methods were adapted and employed are given in articles 1, 2 and 3 (Schønheyder, forthcoming; Schønheyder & Nordby, 2018; Schønheyder, in review).

As I used these methods, I strove for continuous learning and to continuously refine the approaches and techniques proposed by each method. Independent of a specific method, I used the outcomes of the research approaches and the findings of the inquiry to feed back into the different processes (Figure 20). The figure illustrates how methods were employed to develop the Halogen design method collection (HDMC) and to write three journal articles. The findings and observations from one research case were used as input for inquiry for the following case. As I adapted and used a diverse set of methods, each approach could bring complementary perspectives to an overall understanding (Goodman et al., 2011).

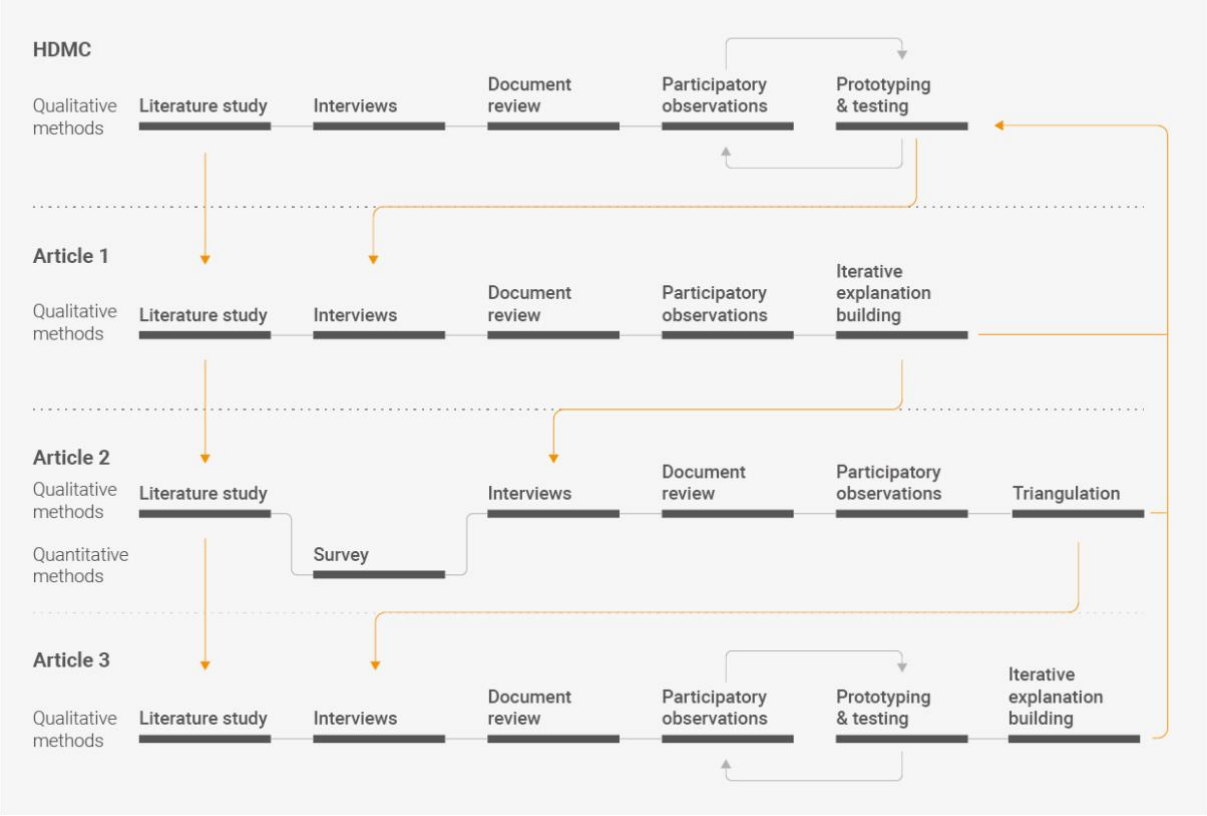

Figure 20. Research cases and methods support and complement each other to bring an overall understanding.

The next section describes how this pragmatic adaption resulted in reflexive and interpretive mapping.

4.9 Reflexive sketching and interpretive mapping

Since this study used a design practice approach, continuous reflections and interpretation were conducted throughout the entire process of the study. This was necessary for designing methods and building explanations in the real-world context. Nelson and Stolterman (2012) argue that interpretation is an essential part of the design process in an unpredictable world. The directions of the interpretations were guided by iteratively sketching out reflections in relation to theory, findings and research aim. I performed this activity throughout my entire research project. However, in the later phases of my research I became aware of the term preliminary creations and discovered how well it matched and explained my particular approach. Yin (2013) states that preliminary creations can be generated by visualising and juxtaposing data in search of patterns, insights, and concepts. In this thesis I will use the term to frame this particular approach.

In line with Deweyan pragmatism, it was important for me to see the preliminary creations in the *contextual whole* of my research. I wanted to observe and reflect on specifics without overlooking details or neighbouring topics in the preliminary creation. Although generating preliminary creations was an organic and overlapping process, it can be broken down into four components: (1) sketching, (2) visual mapping, (3) reflection, and (4) interpretation. At the centre of these four components was the theoretical framework that framed and challenged the preliminary creations (Figure 21).

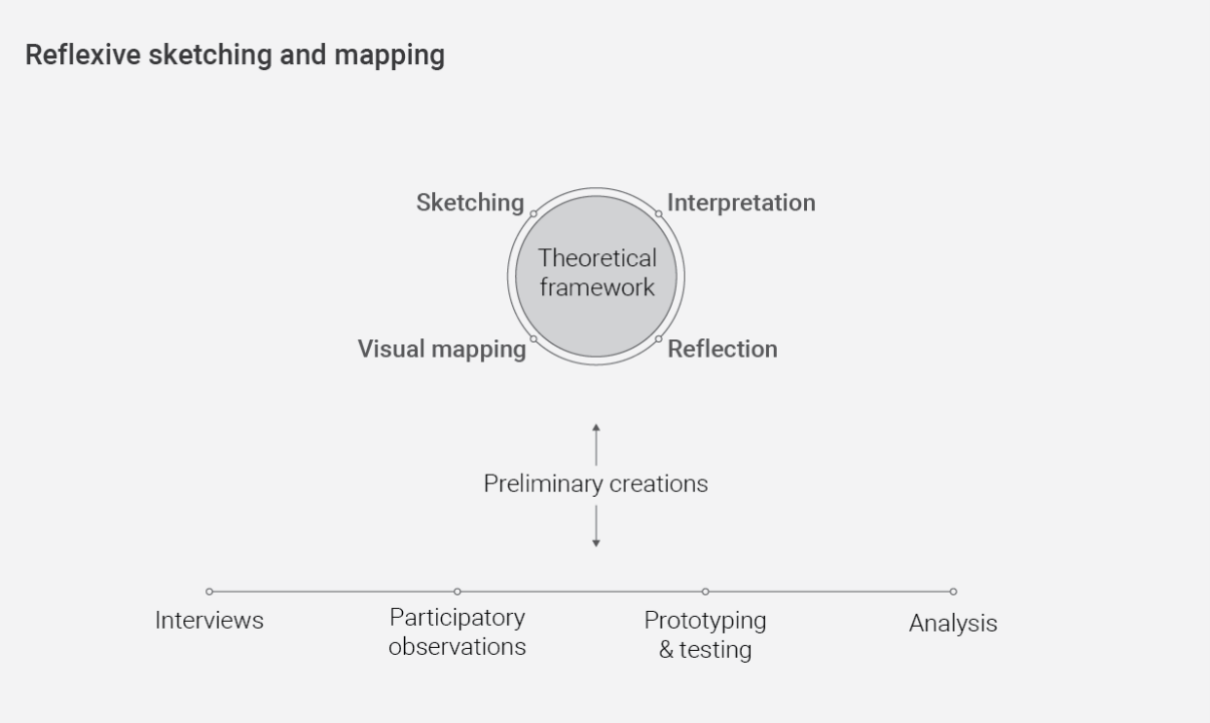

Figure 21. The process of reflexive sketching and mapping.

As the research progressed, this approach became my preferred way to work with the qualitative methods used in this thesis. This process was also a key component in the cycles of reflection, which were used to develop the SA design assessment tool as described in article 3.

The activity of sketching was the core of this approach (Figure 21). Design literature identifies sketching and drawing as central crafts in design (Lawson, 2005). Jones (1970) considers sketching such a fundamental part of the design process that it could be called 'design by drawing.' Although sketching is slower than writing, the combination of sketching and mapping encourages what Schön (1983) calls a reflection with the situation. In this process, words connect with drawings to form spatial images. This particular form of reflection is encouraged as an alternative way of processing research data, since it allows individual elements to be considered in the context of the whole (Sadokierski & Sweetapple, 2014). Schön also famously phrased the act of sketching as a designer 'having a conversation with the materials of the situation' (1983, p. 172). This refers to a designer's thought process while drawing. According to Schön, this design process includes two aspects: *problem solving* and *problem setting*. As described in section 2.2.4, this means that the designers understands and solves the problem simultaneously. According to pragmatic tradition, this process can be made accessible through visual techniques and representations.

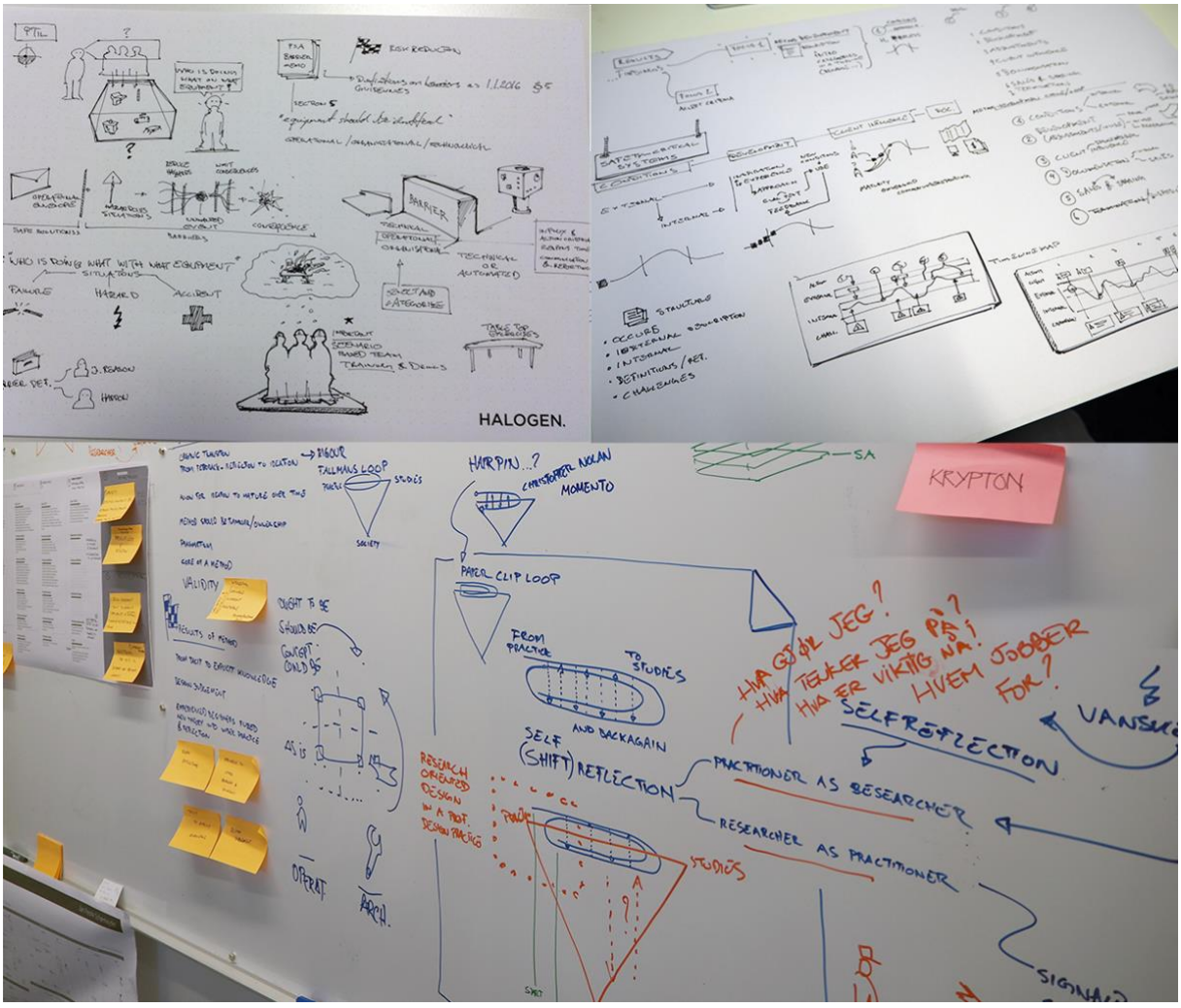

Figure 22. Various levels and stages of reflective sketching and interpretation. Photo credit: Jan Fredrik Schønheyder.

In my approach, problem solving and problem setting allowed me to explore, understand, and address a problem. However, these two processes also served a purpose in helping me allocate appropriate effort to my research activities. As an example, in the *design practice* activity area of the Triangle, the focus is on problem solving. This could be making the design tool, collecting HDMC, or even adapting research methods. In *design studies*, problem setting guided the framing and discussion of various research topics. In particular, problem setting was the focus when framing this thesis. As Buxton states, problem solving and problem setting 'get the right design as well as the design right' (Buxton, 2007, p. 78). Inspired by mapping techniques from systems-oriented design (Sevaldson, 2013); the preliminary creations were organised on large maps, to which they were attached. They were organised to highlight relationships, sequences, and patterns between reflections, creations, and domains. These maps where placed on walls in a room to be observed and reflected upon simultaneously (figure 23). The approach draws upon Dewey´s explanation that before one can act in the world, a contextual whole must be understood and reflected upon (Hickman & Alexander, 2009). In this manner, I could zoom into specific relationships, sequences and patterns without losing the contextual whole of the situation.

Figure 23. Visual maps and preliminary creations reflected and interpreted in a contextual whole. Photo credit: Jan Fredrik Schønheyder and Christoffer Lange.

Nelson and Stolterman (2012) suggest that such patterns create meaning through interpretation. The authors argue that the result of these interpretations can become a starting point for a hybrid form of knowledge that has both pragmatic and theoretical applications (Nelson & Stolterman, 2012). In my case, I employed the theoretical framework as a baseline to further interpret the patterns and preliminary creations. By superimposing theoretical themes and concepts over the preliminary creations, new patterns emerged (Figure 24). These patterns where combined with previous collected data and iteratively interpreted through sketching. In this manner, I performed multiple iterations of critical reflection and sketching which gradually created an understanding of the complete picture. At this point in the process, hypotheses where formulated to highlight or inquire about a particular occurrence. For example, preliminary creations written on post-it notes (Figure 23) and superimposed theoretical patterns (Figure 24), contributed to generate sketches of evolutionary method-development cycles. These sketches where then employed to form hypotheses of how methods are pragmatically used and adapted in Halogen. Dewey explains that only after a contextual whole is understood, then a hypothesis can be framed to transform the situation (Hickman & Alexander, 2009). Note that in this case, the quote “It’s like variations on a theme” formed a hypothesis in itself (Figure 24). This specific quote

demonstrated to be an interesting hypothesis that motivated me to further inquire and develop sketches on how methods are used by professional design practitioners. The result ultimately became the Cyclic Evolution model as described in article 2.

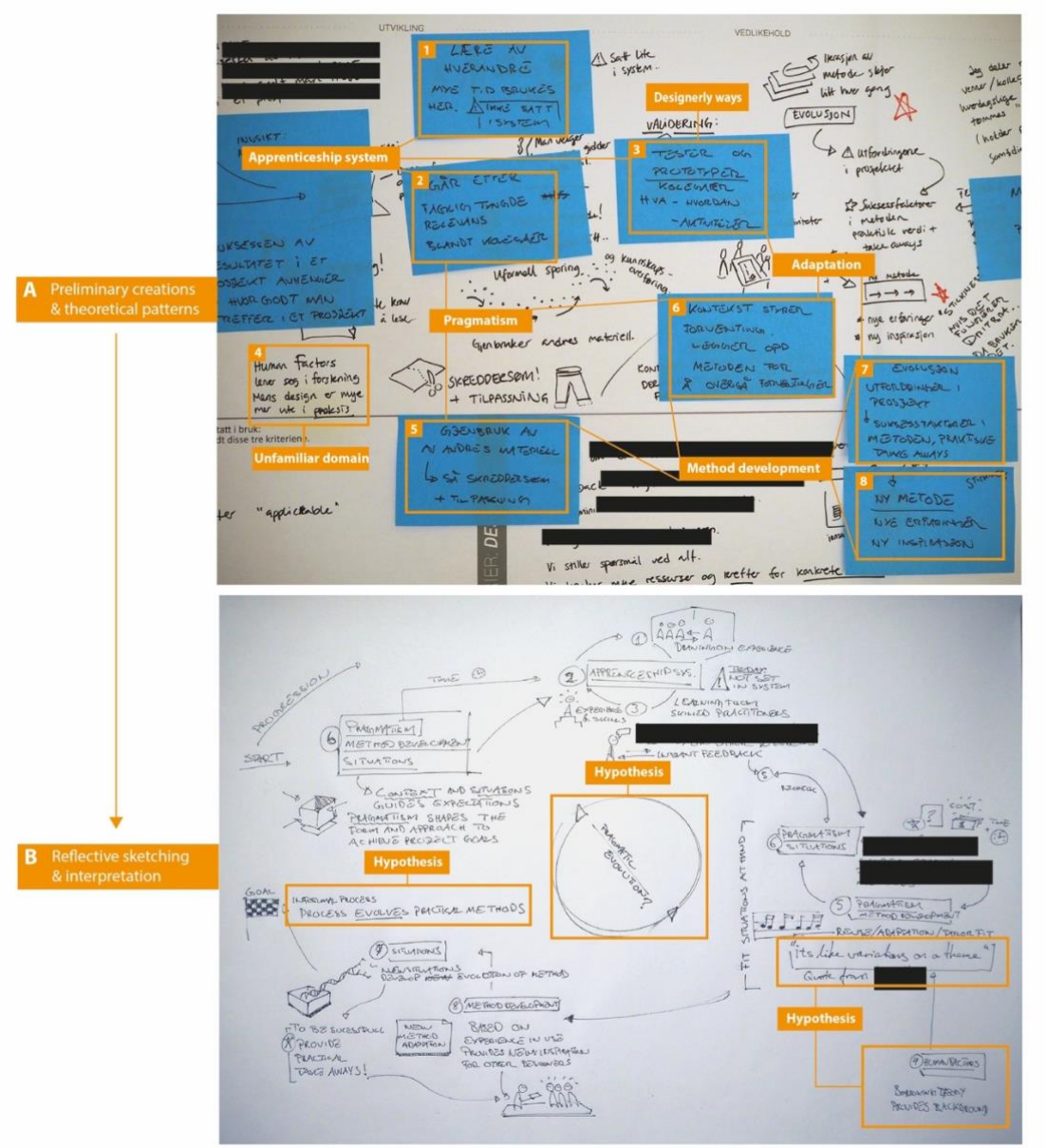

Figure 24. A illustrates preliminary creations with superimposed theoretical patterns and B illustrate how A is interpreted through reflexive sketching and new hypotheses formed.

The sum of these hypotheses and interpretations generated not only new preliminary creations, but also actionable activities to be employed in the research methods. The interpretation of the preliminary creations generated input that was fed back into the visual maps.

4.10 Beyond the Triangle

To address my overarching research aim, I also moved outside the research triangle to conceptualise my research on a higher level. I did this by utilising the concept of dimensions.

Fallman (2008) describes dimensions as a conceptual extreme, positioned outside the whole model, which can be used to create tension between different areas. This can be done by examining the literature and other work to perceive the differences in worldviews among design practitioners and researchers. Fallman (2008) further argues that a dimension can be a useful, powerful tool for generating practical, contextualised, meaningful discussions.

Pullin (2014) also explored the possibilities of the outer space of the model. He went beyond the Triangle to explore and map unfamiliar territory in order to further investigate two design cases. According to Pullin, Fallman supports this kind of explorative evolution of the Triangle in order to shed new light on different aspects of design research. In communication with Pullin, Fallman validates his suggestion of looping outside the model (Pullin, 2014).

Although I think the notion of establishing tension between activity areas is a good idea, this model offers only vague approaches to operationalising emerging discussions. As a general comment, the Triangle in itself can be perceived as generic and simplistic in its form. This leaves the researcher independent in understanding and selecting approaches for interpretation of data and knowledge construction. However, the simplicity and independency in the Triangle might also be the reason to why the Triangle has a broad appeal within the interaction design research community. Nonetheless, in my case as an inexperienced researcher situated in practice, the Triangle created uncertainty and difficulty in understanding what constitutes as new knowledge in the space between practice and theory.

In understanding what constitutes as knowledge production in the space between practice and theory, the term intermediary knowledge is used. Here the goal is to construct understanding, articulations and knowledge of what is key to design practice, such as generative, design concepts, design skills and designerly ways of knowing (Höök et al., 2015). Dindler and Dalsgaard (2014) has introduced *bridging concepts* as a mean to stand in between theory and practice to facilitate knowledge construction in the evolving field of HCI. Employing Deweyan concepts such as situatedness, inquiry and technology, the focus is on articulating implications for design, use and experience of interactive systems (Dalsgaard & Dindler, 2014). The authors draw their work from *strong concepts* developed by Höök and Löwgren (2012) and *conceptual constructs* developed by Stolterman and Wiberg (2010) which also aims to develop intermediary knowledge. However, these three constructs either depart from HCI research or is positioned right in between practice and research. Thus, the knowledge construction is mostly developed from a theoretical perspective. (See Dalsgaard and Dindler for a detailed description of intermediary forms of knowledge in HCI (Dalsgaard & Dindler, 2014).) Further, Höök et al. (2015) recently argued that the field of intermediary knowledge still lacks shared understanding and articulations of this form of knowledge.

To manage the Triangle and to ensure that my research is of relevance to practice, I departed my overarching reflection from the Design practice area. Inspired by Pullin and the theoretical framework in *bridging concepts*, I also decided to employ pragmatism to explore beyond the Triangle.

4.10.1 Adding pragmatism to the Triangle

To go beyond the Triangle, I have introduced pragmatism as the outer dimension so that the three articles can be conceptualised as a whole (Figure 25). Drawing on the primacy of practice, this dimension is used to understand, explore, and evaluate theories and ideas so they can develop into for practice-based actions. This means that theory and practice must not be viewed separately; they must be merged through experience to help us grasp and act in the world (Peirce, 1974). In a recent summary of Pierce, Dalsgaard (2014) stated that our experience in practice takes precedence over doctrines.

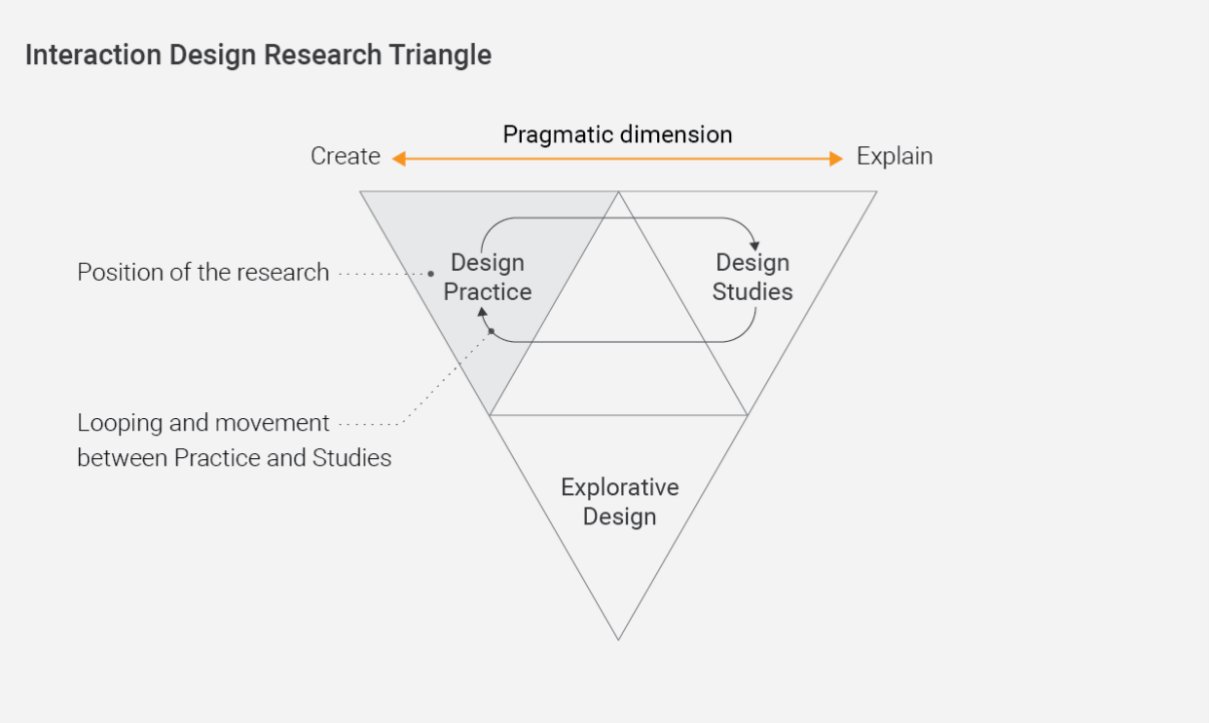

Figure 25. The pragmatic dimension of the interaction design research triangle.

To create tension between areas in the triangle, Fallman (2008) suggests charging each end of a dimension with conceptual extremes that fit the activity areas. Drawing from his own experience and design theory, he provides examples of extremes that may promote the emergence of discussions from the triangle. Based on Fallman´s (2008) proposed examples, I have placed *change* and *explain* as two conceptual extremes at each end of the pragmatic dimension. In design practice, *change* implies proactive activity with the aim of creating and changing a situation. In design studies, on the other hand, the goal is to understand and explain a situation in order to predict it. Other examples exist, but in the context of pragmatism, *change* and *explain* are two conceptual extremes from design that I believe resonate with the core tenets of primacy of practice.

4.10.2 Surfacing a bridging theme

Ensuring that the three articles I have written shared one general conception warranted an iterative approach. I used triangulation to surface concepts that bridges the articles and answers the research questions. To do this, I drew on affinity diagramming (Beyer & Holtzblatt, 1997) to visually group findings and iteratively develop explanations (Yin, 2017) to finalise a presumed explanation of the subject.

The triangulation involved analysing the progress using the pragmatic dimension of the Fallman triangle. Although both affinity diagramming and iterative explanation development are not well documented in operational terms (Gray et al., 2014; Yin, 2017), their practical and complementary qualities proved to be efficient and useful for surfacing concepts, especially when combined with the pragmatic dimension. In this process, research activities were divided into three sequential phases: (1) individual and explorative, (2) peer review workshop, and (3) converge and synthesis (Figure 26).

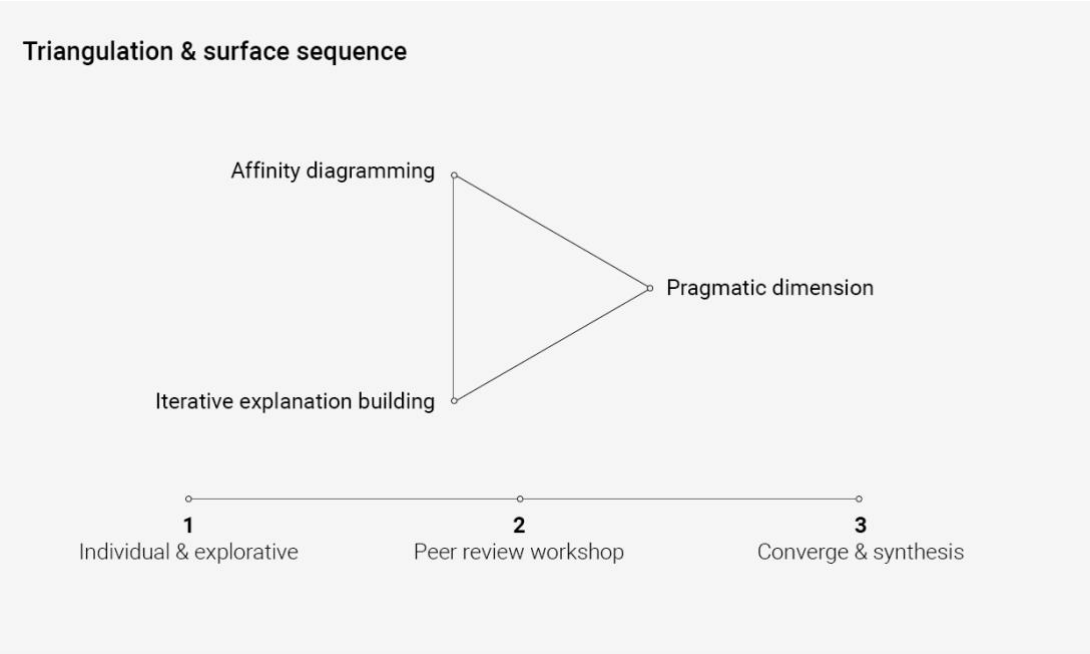

Figure 26. The triangulation and sequence of surfacing a bridging concept.

Sequence 1

The first sequence involved a designerly approach to the triangulation. I iteratively explored, generated, and matured alternative concepts that could explain and bridge my research articles. In this sequence, I also made tentative theoretical statements and developed models, which I then compared to my studies.

Sequence 2

The second phase involved a peer review workshop that included researchers and design practitioners. The workshop participants consisted of seven experienced design practitioners and three design researchers, all connected to Halogen. The goal of the workshop was, first, to disseminate and critique the research in order to develop an explanation with practice-based relevance and impact, and, second, to reduce the risk of bias and parochial vision in my research. Schön (1983) defines parochial vison as a state in which one fails to see and understand the whole due to specialisation and routine. This topic is discussed further in article 3.

The participants read all three articles prior to the workshop. The only instructions they received were to read the articles entirely and to reflect on their individual relevance and impact for everyday practice. These instructions were given to prepare the participants and manage their expectations of the workshop so as to minimise cognitive load during the

reading process. I used 'Interview Guided Mapping' (Schønheyder, forthcoming) to create visual maps and question cards to establish a common surface to identify, develop, and discuss ideas about the material (Figure 27).

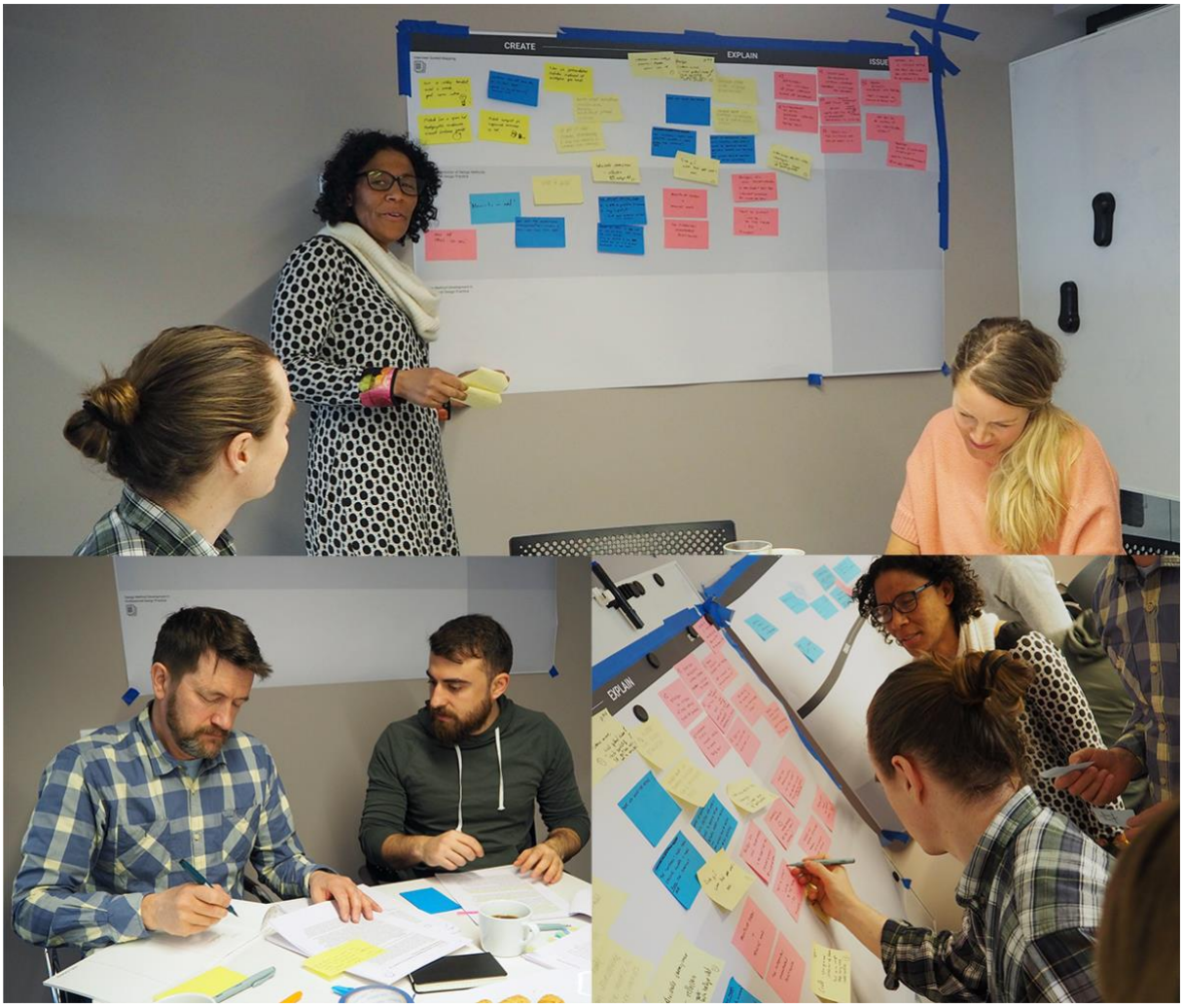

Figure 27. A workshop with practitioners and researchers at Halogen. Photo credit: Jan Fredrik Schønheyder.

The workshop consisted of two parts. First, the three articles were discussed and examined as individual contributions. Each article was evaluated for its capacity to enable *creation* and *explanation* in the real-world context of unfamiliar domains. Each article's relevance to and impact on practice and research was discussed, along with the implications of the findings; the core concepts were also identified. In the second part, the 'golden thread' connecting the articles was identified. This involved developing proposals and models to clarify each article's relevance for everyday practice and potential impact on future research.

Sequence 3

In the third and final phase, the concepts and results from the first two phases were combined and synthesised. Working by myself, the material from the first two phases was compared and further developed through iterative triangulations. A large part of this work consisted of iterative revisions of statements and of integrating the findings with the concept. The goal was to surface and explain a concept that bridges the three articles and

also to express my own position on what constitutes meaningful, relevant, practice-based research.

This section has described the steps I used to surface bridge the reflections and themes in this thesis. The results of this approach are described in chapter 6, Contributions.

4.11 Research limitations

The research approaches and methods employed in the included articles have been subjected to peer reviews and discussions in academic seminars and journals. However, there are limitations to these approaches, of which the most notable is my employment at Halogen. In this section, rather than address the papers individually, I will discuss my approach and its positioning in design practice in the interaction design research triangle.

As an industrial PhD fellow, my position in the *design practice* activity area involved my roles as a researcher and a practicing designer at Halogen. This close relationship between the researcher, the setting, and the respondents can be problematic and can result in bias (Robson, 2011). Fallman (2008) describes such a role as primarily synthetic due to the researcher's involvement in a particular design situation. In this synthetic role, a researcher faces numerous practical concerns that shape the design research (Fallman & Stolterman, 2010). These practical concerns, which may include the different skills and worldviews of other design members, the researcher's contractual relationship with the client, and the fact that projects sometimes require a significant length of time, can govern the direction of the research. As a result, in this particular form of design research, rigour and relevance must be understood in a certain way (Fallman & Stolterman, 2010).

The concept of rigour in *design practice* represents a limitation in itself. Fallman and Stolterman (2010) point out that the *design practice* approach is about understanding the situation in order to create a design that works. In their words, 'if the final design makes sense and is useful, that is, if the design is relevant, then rigour is less of an issue' (Fallman & Stolterman, 2010, p. 270). Thus, in this approach, there are no predetermined conditions that define rigour.

Taken together, rigour and the synthetic role of a designer create a serious conflict. Because of my employment and previous position in the company, it is possible that my new synthetic role caused confusion amongst the design teams. This raises a potential ethical issue: My co-workers' relationship with me might have coloured their responses to me as a researcher. This kind of situation can damage a study's reliability and generalisability (Randall, Harper, & Rouncefield, 2007).

This has been a central concern throughout my research. As Archer (1995) argues, it is nearly impossible to conduct a systematic enquiry of the real world while avoiding investigation contamination and interference. However, in an effort to address these challenges, I have systematically combined multiple approaches and theories. Such an approach can overcome inherent biases and help make previously unspoken assumptions explicit (Creswell, 2013; Goodman et al., 2011).

As previously described in chapter 4.5, an examination of design research in *design practice* requires a solid, clear understanding of the specific context of that research. In this thesis, I have attempted to be as clear and transparent as possible when describing the context of my study. This includes my descriptions of the field setting, of how the data was collected, and of the process of interpretation. I hope these clear descriptions leave my research open for scrutiny in terms of *interpretive possibilities* (Seamon, 2000). By this I mean that the research cannot be tested based on a repetition of the context, procedure, and findings, because my mode of inquiry, claims, interpretations, and articulations are my own.

The next chapter presents the results and main findings from my research in design practice.

5 RESEARCH CASES AND MAIN FINDINGS

This chapter presents the research cases and main findings from this industrial PhD project. The aim is to present the results and provide a background for the contributions and overarching reflection of this thesis. First, the process of developing a proprietary method collection for use in the design of safety-critical systems will be described. Then, three journal articles and their main findings will be presented. Next, the research findings from my research in a professional design practice will be described. In summary, the chapter concludes with a discussion of the quality of the research.

5.1 The HDMC, design methods for safety-critical systems

I developed the Halogen Design Method Collection (HDMC) for safety-critical systems as part of my research. The HDMC is proprietary knowledge that belongs to Halogen. Therefore, the research and results of this collection will not be published at this time. However, an outline of the research process and of the undisclosed results are provided below.

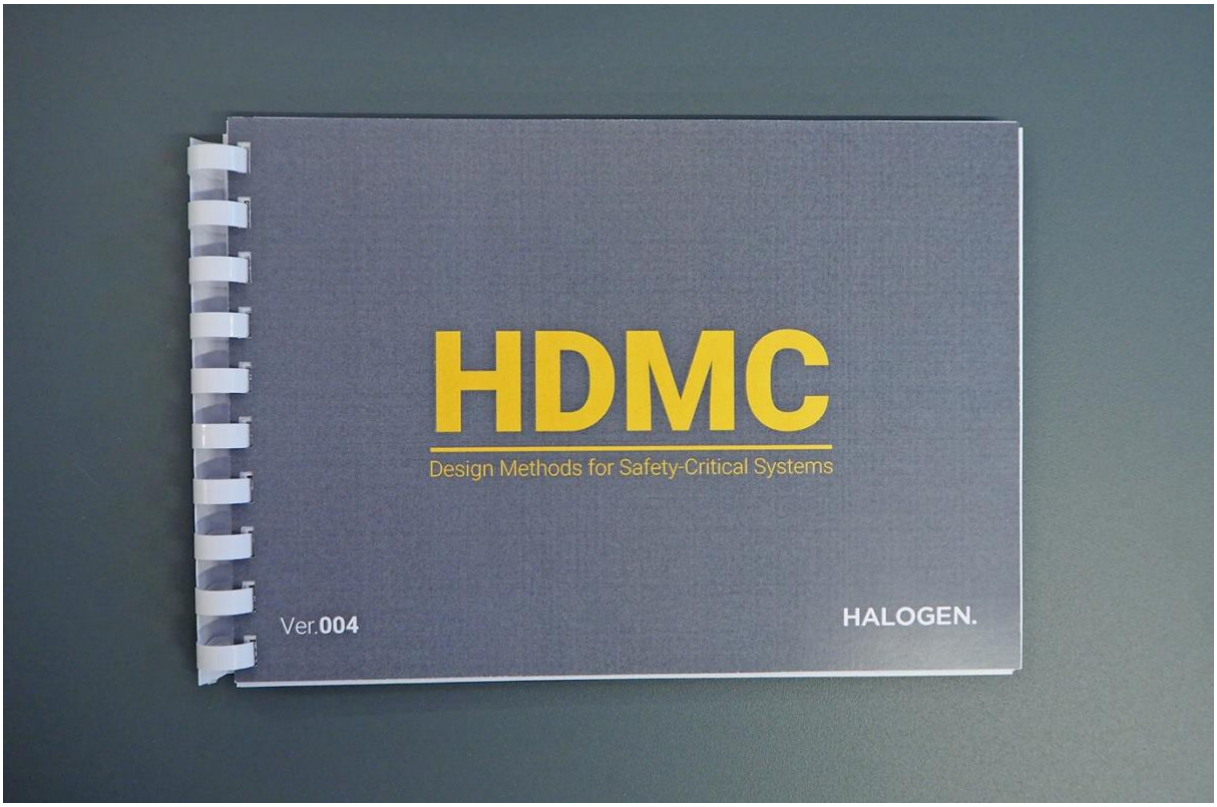

Figure 28. Prototype version number 4 of the HDMC. Photo credit: Jan Fredrik Schønheyder.

The HDMC consists of 30 multidisciplinary design methods for use in the early phases of a design process (Figure 28). The HDMC describes different methods, approaches, and tools for designing safety-critical systems, from start up, insights, and analysis to the conceptualisation and assessment of design solutions. The HDMC was motivated by the practical implications and challenges design practitioners at Halogen face when conducting design work in complex, unfamiliar environments. As Lurås et al. (2015) point out, these challenges are not to be taken lightly due to the constraints and potential consequences of work on safety-critical systems.

To address these challenges in a practical, scholarly manner, I conducted several types of qualitative research. Through literature studies, interviews, observations, and document reviews, I identified and reviewed material from 27 proprietary design methods. As this information emerged, I started to understand the various contexts in which different methods are used at Halogen (Table 2). The results of this document and material review were also used in the study described in article 2.

Insight phase	**Concept phase**	**Design phase**
Project insight mapping	Mood board workshop	Iterative detailed workflow prototyping
Political and operator stakeholder mapping	Explorative workflow sketching	Pilot prototyping
IO-MTO analysis	Biased concept prototyping	SA design evaluation
Relations mapping	Concept ideation workshop	
Semi-structured interview	Workflow mock-up	
Visual interview mapping	Interface layout mapping	
Field observations	Interaction philosophy mapping	
SA and team SA field observations	Scaled workflow mock-up	
Roles and context mapping	Contextual concept designing	
Specific and complete timeline mapping	Probe prototyping in context	
ZIP analysis	Holistic concept and operation philosophy testing	
Frequency and criticality mapping	SA concept design evaluation	

Table 2. Design methods used in the design of safety-critical systems.

The results of the interviews, the observations, and the material review were triangulated with the literature review to identify each method's relevance in content and use. The existing methods were then iteratively restructured, redesigned, and categorised into what became known as the Halogen Design Method Collection. A central part of this process was developing and supplementing the collection with SA theories and methods. This was an important part of the redesign process, since SA is believed to play a significant role in the design of user-friendly systems for high-risk environments (Jones, 2015).

The HDMC collection was developed and field tested over three iterations by design practitioners at Halogen from the spring of 2016 to the spring of 2018. The field tests were conducted in commissioned projects conducted in the Halogen offices and at the clients'

facilities. The iterations were further tested in remote onshore and offshore locations in Norway, Singapore and the US. The data collected during the developing and testing of the HDMC collection were used in all three articles. In particular, the literature review and the material review became a foundation for the other articles to build and expand upon. The methods and models developed in this PhD are included in the current version of the HDMC.

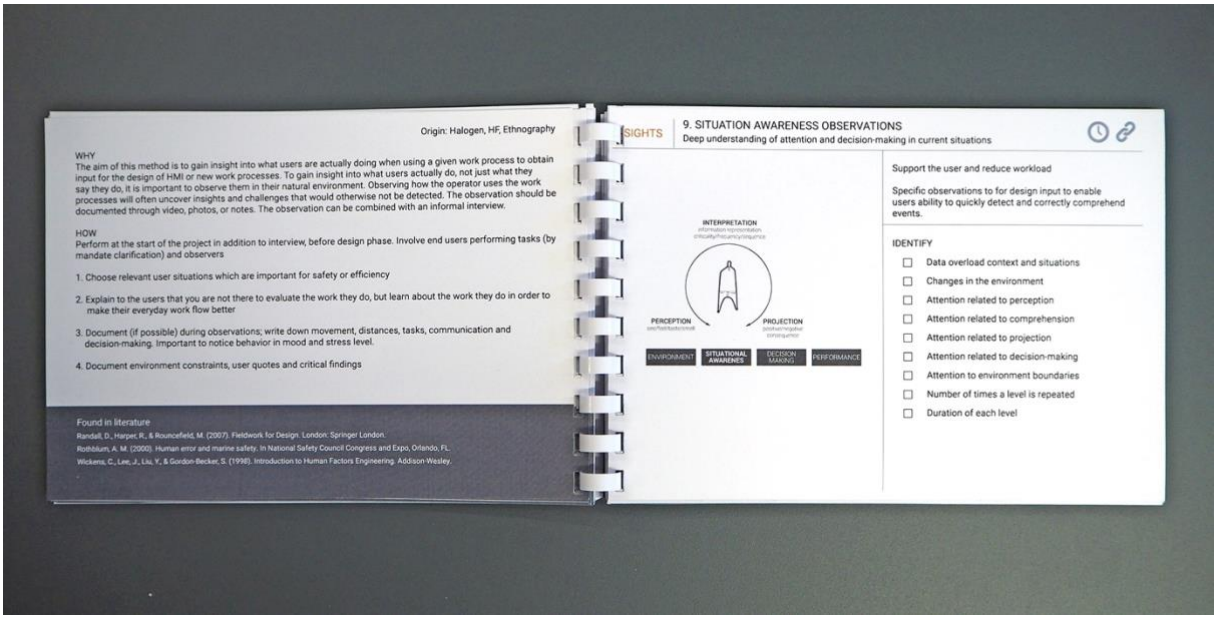

Figure 29. Front and back of the method cards. Photo credit: Jan Fredrik Schønheyder.

As previously mentioned, the HDMC consists of 30 methods. Here, each method is presented on an individual card. The front page explains the purpose and outcomes of the method (Figure 29). The back provides a background to why the method is important and a description to how the method can be performed. References to relevant literature and research is provided at the bottom of a card. In this manner, practitioners have the possibility to examine the deeper mechanisms behind the method. The paper-based format of the collection makes it accessible to bring into high-explosive and data-sensitive areas where electronic devices are prohibited.

Each collection is accompanied with a self-report card for designers to evaluate and feedback their experiences with the methods. The aim is to achieve a living document where relevance and experience is iteratively updated. In addition to support design processes, the HDMC is currently used in Halogen as a framework to guide individual competence and method training programs.

5.2 Journal articles

This thesis is the result of three journal articles that were developed from 2016 to 2018. This section presents a short summary of the three articles and their main findings. The complete articles are located in part 2 of this thesis.

5.2.1 Article 1

Schønheyder, Jan Fredrik. 'Interview Guided Mapping: Qualitative Inquiry in Professional Design Practice.' *Formakademisk.* forthcoming.

The article introduces the Interview Guided Mapping (IGM) method, a qualitative inquiry approach used to support the design of safety-critical systems. The article presents a practice-generated design method to the design research community and discusses that method. The motivation for the article was the lack of in-situ empirical descriptions of design practitioners' methods, tools, and activities (Goodman et al., 2011). Using a first-person perspective and semi-structured interviews, the paper describes the IGM process in the context of professional design practice. It introduces a step-by-step process which design practitioners at Halogen use to conduct visual inquiry and early analysis in the domain of safety-critical systems (Figure 30). The article presents examples of templates and frameworks to further describe the mechanisms in conducting a visual inquiry. This offers the reader an opportunity to perform inquiry into unfamiliar domains.

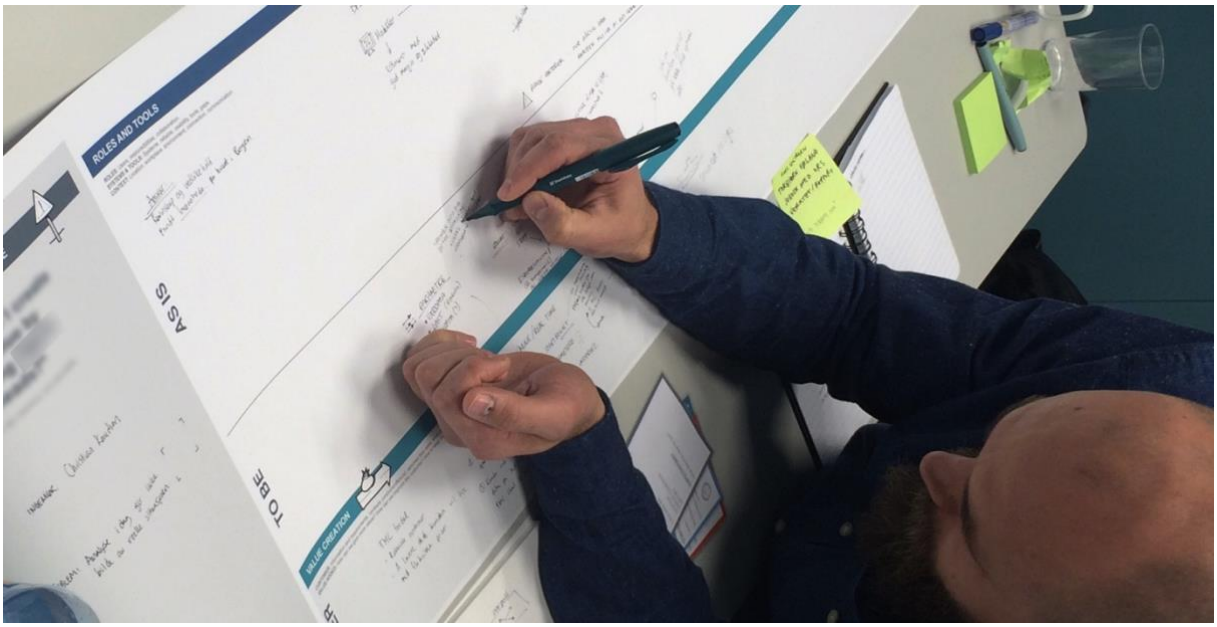

Figure 30. A designer annotating and sketching during an interview. Photo credit: Amra Softic.

The article then theoretically discusses how sketching and visual mapping may support reflection and help design practitioners and clients develop a common understanding of a design problem. In this process, the act of sketching in particular supports problem setting (prior to problem solving) in unfamiliar situations and domains. The article further explores how visual inquires can support interviewees´ appreciation of the interview situation (Figure 31). Later, by connecting visual representations to words, this approach has the potential to uncover hidden processes in wicked problems. The implications of this method and its transferability to other design contexts and further work are also considered.

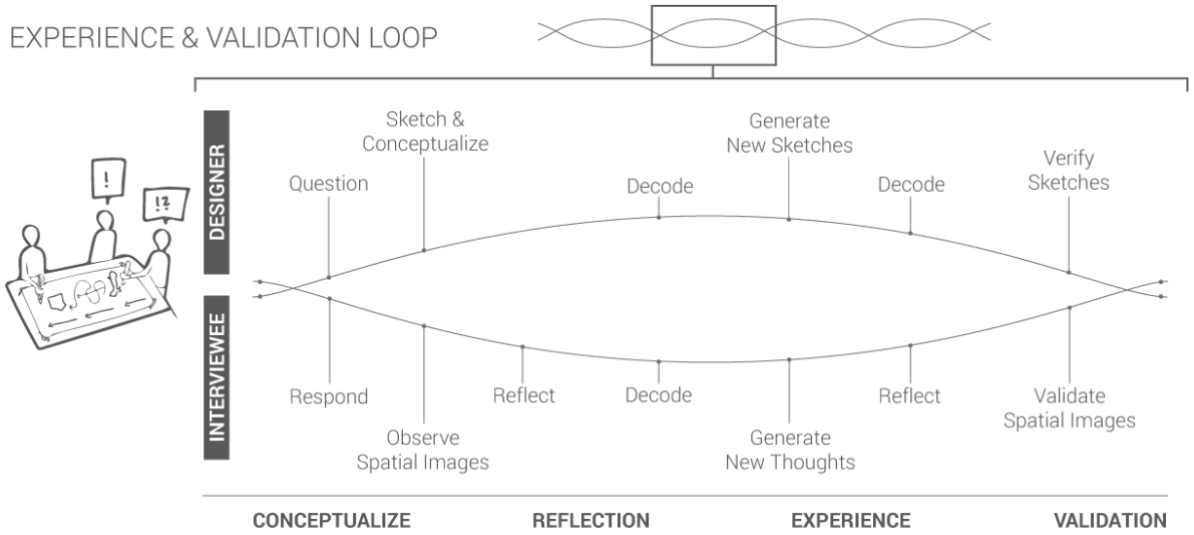

Figure 31. Illustration of the experience and validation loop between a designer and the interviewee.

Main findings

Article 1 expands on current knowledge about qualitative inquiry.

It also explains how sketching can be used to understand wicked problems and to establish a common framework for discussion and formalisation. The main findings are:

1. A shared visual space enhances mutual knowledge construction.
2. The visual space exposes hidden processes and make them explicit.
3. Sketching reduces inhibition and the interviewer effect.
4. Sketching is a pragmatic and analytical tool that reduces the time required for post-interview activities.
5. Visual interviews require skills in decoding verbal accounts and sketching techniques.

The IGM approach and findings described in this article were employed to collect and analyse data in the following two articles.

5.2.2 Article 2

Schønheyder and Nordby. 'The Use and Evolution of Design Methods in Professional Design Practice'. *Design Studies* 58 (1 September 2018): 36–62. https://doi.org/10.1016/j.destud.2018.04.001.

This article investigates how design methods are developed and applied at Halogen. The article addresses two main issues found in design literature. First, most methods proposed by researchers are not applied in professional design practice because they do not account for real-world contexts and lack applicability (Dickson & Stolterman, 2016). Second, practitioners appear to disregard the rigor and knowledge of proposed methods and lack the skills to apply analytical frameworks that are more difficult to use (Rogers, 2005). This article uses a mixed methods approach and presents a number of practical and theoretical developments in understanding how professional designers use design methods. To ensure rigour and objectivity, the article was co-written by my supervisor, Kjetil Nordby, who acted as an independent critical reviewer.

In contrast to existing literature, our analysis revealed that design methods are used in a coordinated, conscious approach through pragmatic, cyclic evolutions (Figure 32). Especially in unfamiliar situations and when wicked problems occur in safety-critical systems, three factors are central to a cyclic evolution: adaptation to fit the situation at hand, the designer's skillsets, and the organisation of design activities. The article explains how these factors contribute to a designer's decision to evolve or discard a method from one project to the next. To clarify the findings, the mechanisms and characteristics of this decision are abstracted and visualised in a model that represents the cycle described in the article.

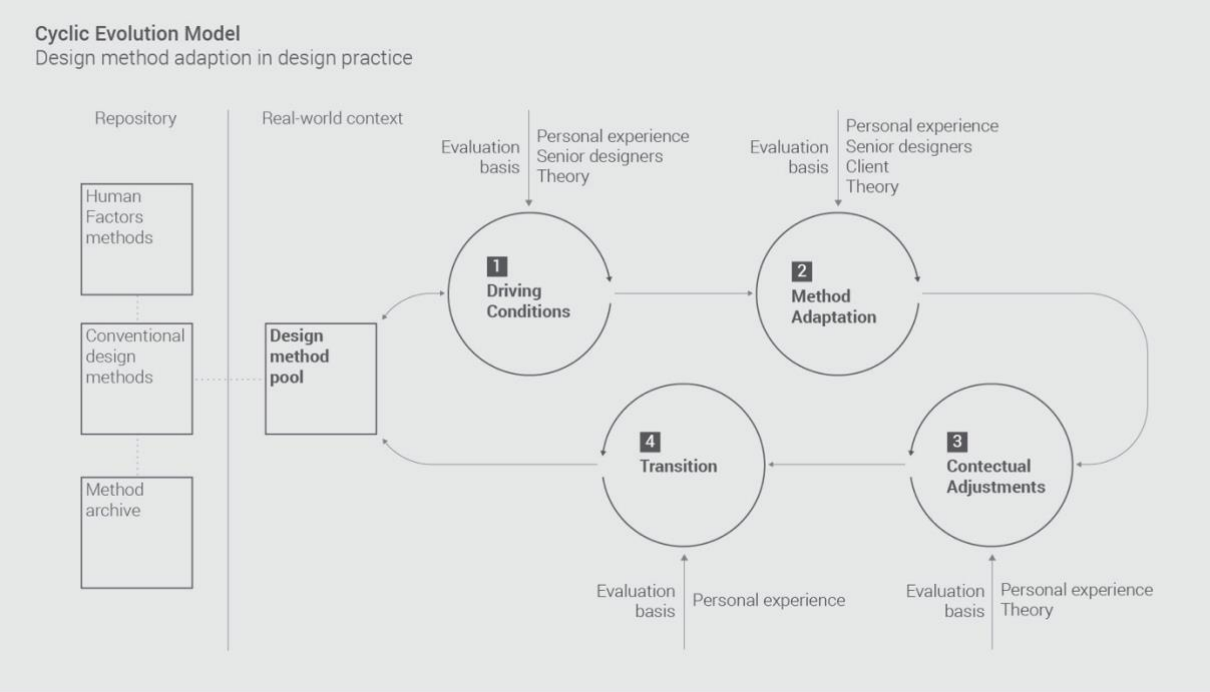

Figure 32. The cyclic evolution model illustrating how design methods are developed and adapted in professional design practice.

The article also proposes the pragmatic evaluation model as a consistent framework for cyclically evaluating and evolving design methods in professional design practice (Figure 33). Three theoretical principles and four heuristics are used to evaluate a method in use based on its feedback and impact. The proposed model can provide opportunities for research that seeks to explain how design methods can be adapted and evolved to support professional design practice.

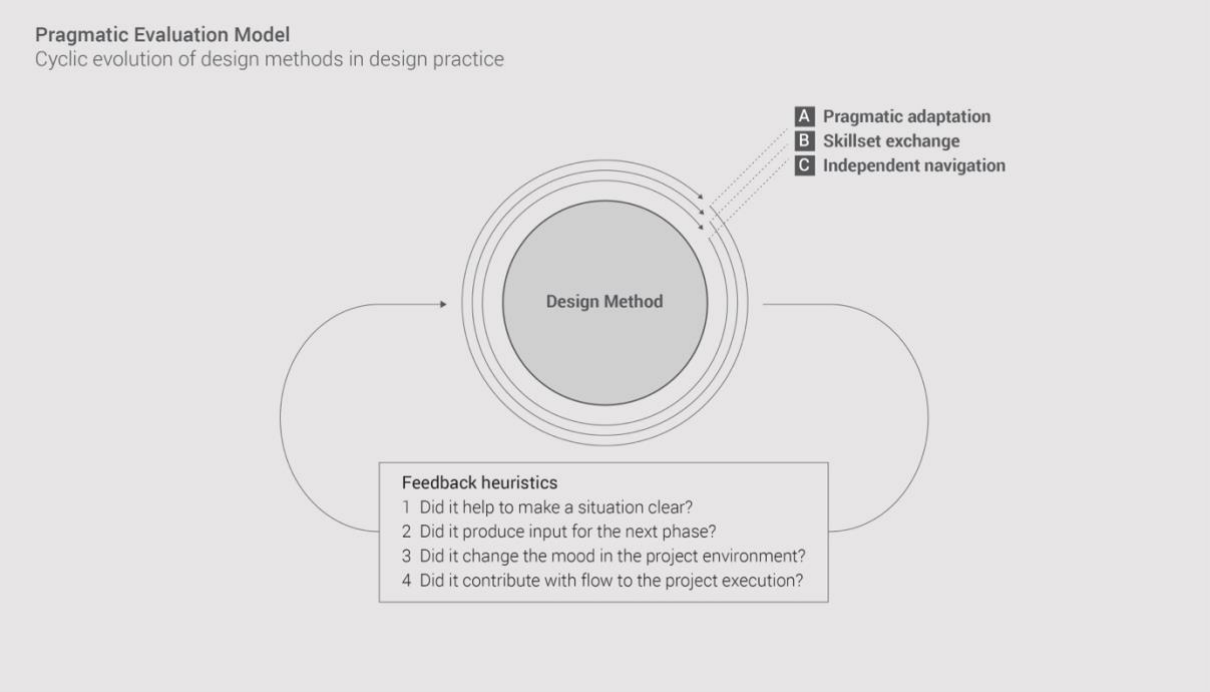

Figure 33. The pragmatic evaluation model illustrating how design methods can evolve in design practice.

Main findings

Article 2 sheds new light on current understandings of methods in design practice. The main findings are:

1. Design practitioners at Halogen use design methods extensively in a conscious and co-ordinated manner.
2. Design methods are developed through pragmatic, user-centred approaches.
3. Design methods are evolved through cyclic evolutions from one project to another.
4. Design methods are multidisciplinary developed, which means they can contribute understanding and argumentation even in unfamiliar contexts.
5. Design methods are adapted to fit individual designers´ skillsets.

The two models and findings described in this article were employed to as an analytical framework for the following article.

5.2.3 Article 3

Schønheyder, Jan Fredrik. 'Designing Relevant Methods: A Case Study on Iterative Method Development in Professional Interaction Design Practice.' In review at International Journal of Design.

The article describes a case study that explores rigorous method development in the context of everyday practice. Like the two previous articles, it was motivated by the lack of in-situ knowledge of design practice and the lack of practice-relevant design methods. The article focuses on appropriate methods for the design of safety-critical systems. The literature suggests that professional designers often develop their own methods to meet the needs and constraints found in practice (Dickson & Stolterman, 2016). The article addresses the

problem that most design practitioners are not scientifically trained and may lack the theoretical understanding to develop adequately rigorous methods (Rogers, 2005).

The article presents an in-depth account of the development and testing of a tool to support design practitioners in a real-world design project. The case study describes how a practice-generated method was selected and how rigour was iteratively introduced using a pragmatic approach to accommodate the field setting. The development process, which involved a project commissioned by the FFI, lasted over 12 months. The article also describes how SA theory was translated into practical heuristics. This is significant because it can help design practitioners better understand and establish vocabulary for an unfamiliar theory. The result was a SA concept design assessment tool to support and validate the translation of analysis to concept designs for safety-critical systems (Figure 34).

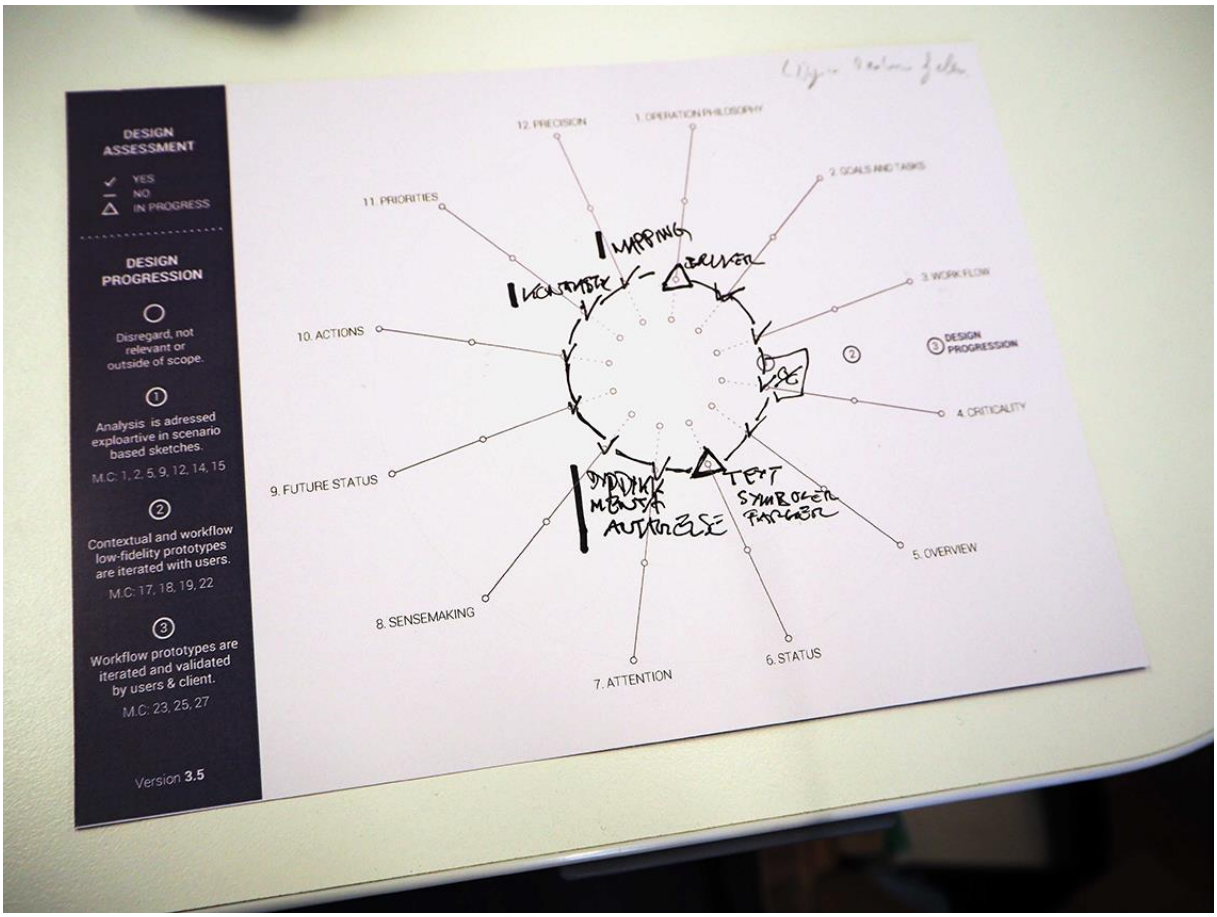

Figure 34. Used assessment card for evaluation of an early concept design. Photo credit: Jan Fredrik Schønheyder.

A conceptual framework for method development in professional design practice is introduced through an iterative process of explanation development. The framework provides 12 concepts that focus on the use of methods, development process and goals of real-world method development (Figure 35). The proposed conceptual framework presents opportunities for practitioners and researchers to improve design methods in practice.

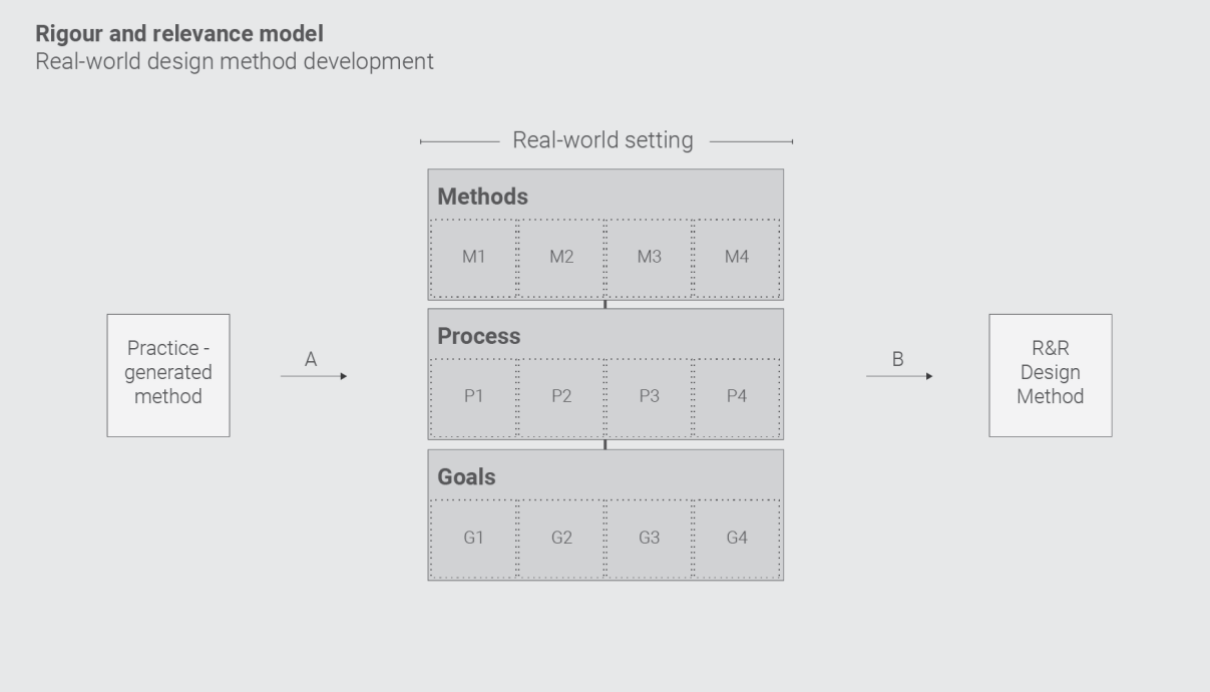

Figure 35. Illustration of the proposed conceptual framework for real-world method development.

Main findings

Article 3 expands current knowledge about method development designed to support professional design practice. The main findings are:

1. Inexpensive and analogue design tools demonstrated an effective and low-barrier approach for implementing a method in a real-world setting. Further, the analogue format had an appreciative and practical value in use that benefitted the outcomes.
2. An iterative user-centric approach for understanding and involving practitioners in the process gradually trained the practitioners in use of the design tool iterations as a design method.
3. Through this training process, unfamiliar theory was introduced and iteratively learned through practical application.
4. Dual perspectives in the cycles of reflection supported the research to maintain rigor and relevance during a long development process.
5. Having a fundamental understanding of a practice generated method provided valuable insights into understanding practitioners' needs and requirements for relevance in everyday use.

5.3 Research findings

This section expands the research findings highlighted in the articles. As discussed in chapter 4.3, Design research models, my specific research context encouraged me to employ a research model with clear communicative and practical capabilities. The following findings focus on my experiences and the results of pragmatically utilising the interaction design research triangle to conduct in-situ research at Halogen.

5.3.1 Managing the synthetic role in practice

In *Design Practice,* Fallman (2008) suggests that the researcher should act first and foremost as a practicing designer. He calls this dual role a synthetic role, since it engages a researcher in a particular design situation. In my experience, to act first as an interaction designer and then as a researcher was challenging at times. I had to ensure the relevance of my actions for both the research outcome and the design artefact. But I also had to take on the mental workload demanded by this synthetic role. So, in the midst of practicing design, I simultaneously reflected on research activities such as observations and inquiry.

These reflections would often generate questions that directly addressed a design situation. These reflections were noted and sketched in a research diary. I used two different formats: analogue note books for use in restricted areas, and a digital diary created with the application Evernote (Figure 36). I used the file handling formats in the software to categorise the notes thematically and chronologically into separate folders. Analogue sketches and annotations were later scanned and documented in the digital diary. My use of the diary in this manner to scrutinise and reflect on various ideas was framed by Schön´s (1983) notion of problem setting, which helped me understand the various situations.

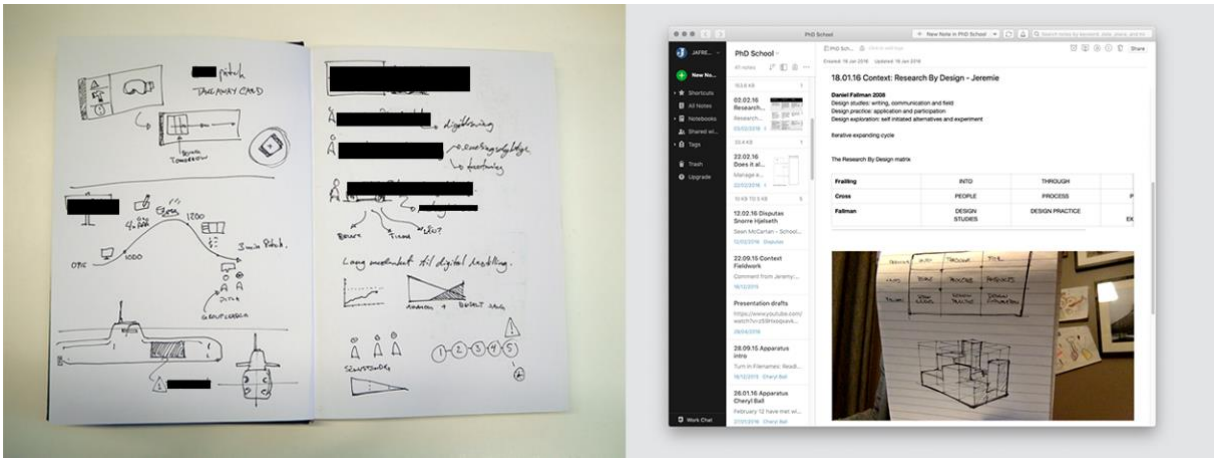

Figure 36. Analogue and digital diary. Photo credit: Jan Fredrik Schønheyder.

To manage the workload and problem setting, I discovered that the Triangle provided a stable and simple framework that I could use as a mental tool. At the beginning of my research, this involved deliberately looping between the perspectives of *practice* and *studies*. This is in line with Fallman´s original concept of using loops to move between activity areas (Fallman, 2008). As the research progressed, I learned to use these loops to actively probe and expand on various aspects of the design and the research. This involved critiquing and reflecting on the design as a researcher and then critiquing and reflecting on the research as a designer. In this way, the loops helped me manage my synthetic role and reflect deeply on the topic.

5.3.2 Horizontal loops

During my PhD research, I was involved in projects that lasted over two years. As described in the case study on method development in practice, I sometimes failed to maintain objectivity and an understanding of the process. Schön (1983) calls this condition parochial narrowness of vison. It is a state in which one fails to see and understand the whole picture due to specialisation and routine. Schön suggests that it results from overlearning in

practice, which can lead to boredom or burnout. In my case, I experienced parochial narrowness of vision after repetitive reflections within the same loop. As I became aware of this state, I gradually expanded the loop in search of alternate approaches. This action often suggested theories or interventions that would be useful for the process. In this manner, new reflections surfaced and then corrected my overlearning by criticising my tacit understanding (Schön, 1983).

Friedman (2000) suggests that an explicit research question should be established for design researchers deeply involved in design work. However, through my loops of reflection, I discovered that it was difficult to pursue one question throughout the research process. Due to real-world constraints, changing situations, and the security restrictions of my field setting, the research question had to be iterated a number of times to maintain its relevance to my current situation.

To accommodate the field setting, my research question became less explicit and more guiding in its nature. This meant that my research focused less on reaching a definite conclusion than on understanding the nature of the problem (Davis, 2014). Subsequently, the research question became a guide to point to new areas that might have practical value for my research position. In this way, I expanded the loops internally and externally to explore new disciplinary areas (Figure 37). I call these *horizontal loops* to illustrate this particular form of reflection.

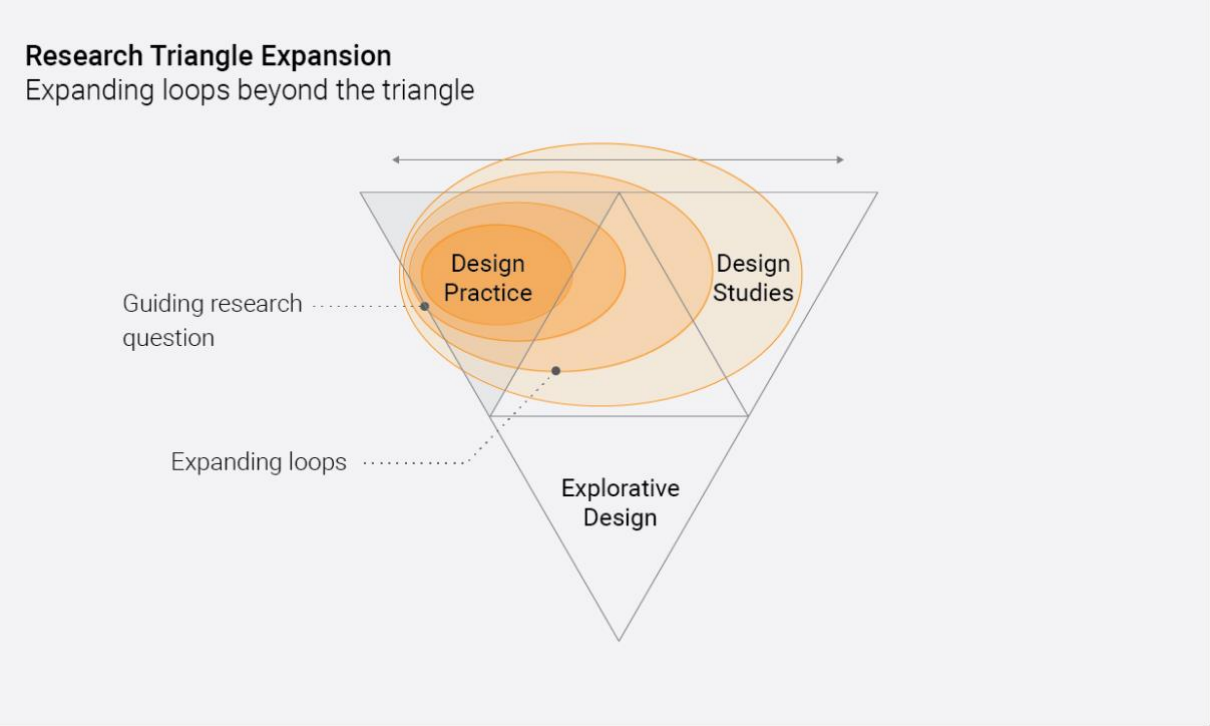

Figure 37. Horizontal loops expanding out of the guiding research question.

These expanding loops helped me in a number of ways. One example is the way they enabled me to systematically research unfamiliar disciplines, such as Human Factors. I used the loops to superimpose theories and principles from influential HF researchers such as Wickens (1998) and Endsley (2011) on design literature and data from my own research and to contrast ideas from the different fields.

This example also represents how I explored and understood pragmaticism in my research. The ever-expanding loops stretched into the space outside the triangle. In this manner, data and theory from *practice* and *studies* were contrasted within a pragmatic worldview. Thus, I reflected on my lived experiences, along with data and theory, and employed Deweyan concepts to evaluate their validity for practice and implications for society at large. At this point in my research, the data and reflections from these loops were sketched out, categorised and placed on visual maps of the research triangle. This enabled me to create diagrams of the contextual whole.

5.3.3 Vertical loops

These activities of guiding looping and reflective sketching can be recognised in Schön´s (1983) concept of *reflection in and on action*. However, as my research progressed, the loops of reflection also involved an explicit awareness of the various domains and disciplines. I call these *vertical loops* to illustrate how I performed this type of reflection into each individual discipline (Figure 38). Depending on the situation, this mode of reflection was a mental activity or a physical one that included sketching diagrams and making preliminary creations. It was not a planned research strategy but an activity that occurred naturally and evolved throughout my study. It later became instrumental in developing and introducing methods into the practice (see article 3).

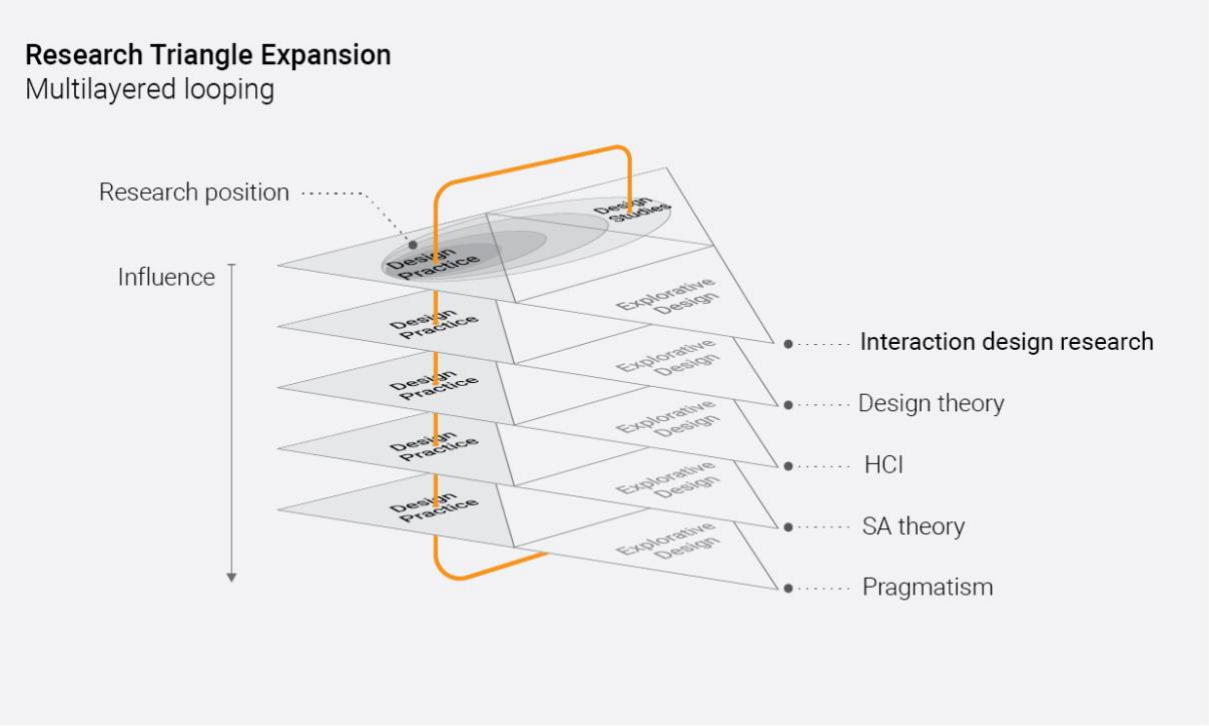

Figure 38. Vertical loops that run through multiple disciplinary layers.

The process of vertical looping consisted of gradually adding disciplinary layers from my theoretical framework. This means that the research would pass through multiple disciplines where particular reflections would emerge, which could then be designed or tested in the field. The outcome of these designs or tests would then generate a new loop of reflection. In such a loop, a reflection would usually pass through layers such as design theory, interaction design research, HCI, HF, and pragmatism. As an example, SA theory was used directly in

observations and interviews to determine the designers' degree of perception, comprehension, and projection of a design situation. In fact, six points of inquiry used in this research were taken directly from the SA framework (Endsley, 2011):

- What do you need to know to make that decision?
- Who do you share it with?
- How do you use this information?
- What is the pain-points related to this information?
- How confident are you about this information?
- What would you ideally like to know?

The three levels of SA provided a framework for categorising and explaining designers´ actions and reflections related to using design methods in various situations. The outcome would then be contrasted with pragmatism before being looped over to the other layers. As a result, data and interpretations were iteratively triangulated to both explore and critique own reflections.

5.3.4 Clear and visual communication

The looping between *practice* and *studies* did not only require me to expand my research and knowledge of other disciplines and domains. It also enabled in-person interaction and communication among these communities. This involved participating and holding presentations in HF conferences, discussions with HF authorities, presenting at IxDA seminars and giving guest lectures at AHO and the HF department of the Norwegian University of Science and Technology. As Pullin (2014) points out, an interesting aspect of the Triangle is its potential to promote interactions with individuals and disciplines outside of design research.

I have also experienced this aspect of the Triangle in my own research. The simplicity and clarity of the Triangle makes it a useful tool for explaining and discussing elements of my research to colleagues at Halogen as well as other researchers, clients, and legislative authorities. At Halogen, the model was used to explain my research, manage expectations, and plan research activities with management. The Triangle was usually drawn on paper or a whiteboard to document activities and outcomes. In discussions and peer reviews with fellow researchers, the Triangle also contributed to nuanced and valuable discussions. Drawing loops between *practice* and *studies* helped reduce misunderstandings of different perspectives and worldviews. The Triangle served as a visual common platform that we could gather around. This helped me uncover another aspect of how I used the model in my research.

5.3.5 Expanding the triangle by removal

In this thesis I have relied heavily on Fallman´s framework, and above I have presented some of the benefits the Triangle provides. On reflecting on this use, I have made certain thoughts on this framework's presence in my thesis. During my initial research phases and the PhD school, I experienced a discrepancy between my world view and the scholars at AHO. Here I had difficulty in understanding and aligning established theoretical frameworks and approaches with limitations and constraints of my own particular research context. Although this might be normal for novice researchers, the lack of explicit vocabulary to communicate my industrial PhD context was frustrating. However, as I discovered the framework of

Fallman I gained a sense of support and understanding in the Triangle to articulate my particular research context. As a result, the framework contributed to act as a common ground between scholars at AHO, me and Halogen. I believe this is one of the key reasons to why the framework appeals to me.

However, as discussed in chapter 4.10, the simplicity of the framework can also be its weakness, especially in relation to operationalizing research and day-to-day communication between researchers and practitioners.

As I used the research triangle over time, I realised that I was not using the third activity area in the model. The *explorative* activity area is designed for exploring societal design and asking 'what if?' based on theories; more importantly, it is often self-initiated and not commercially driven (Fallman, 2008). Fallman and Stolterman (2010) elaborates by explaining that the activity area supports exploration and problem setting, rather than problem solving. I would argue that this particular approach is also a substantial part of what composes as designerly activities in the *practice* activity area. Thus, 'what if?' should not exclusively belong to the *explorative* activity area but be an equal component in the *practice* activity area. Nonetheless, based on my interpretation of the *explorative* activity area, I decided that the *explorative* activity area did not offer any practical value that were relevant to my research. Thus, since the *explorative* approach is positioned outside of commercial interest, I removed it from the model, and in the process, established my own adaptation of the research triangle.

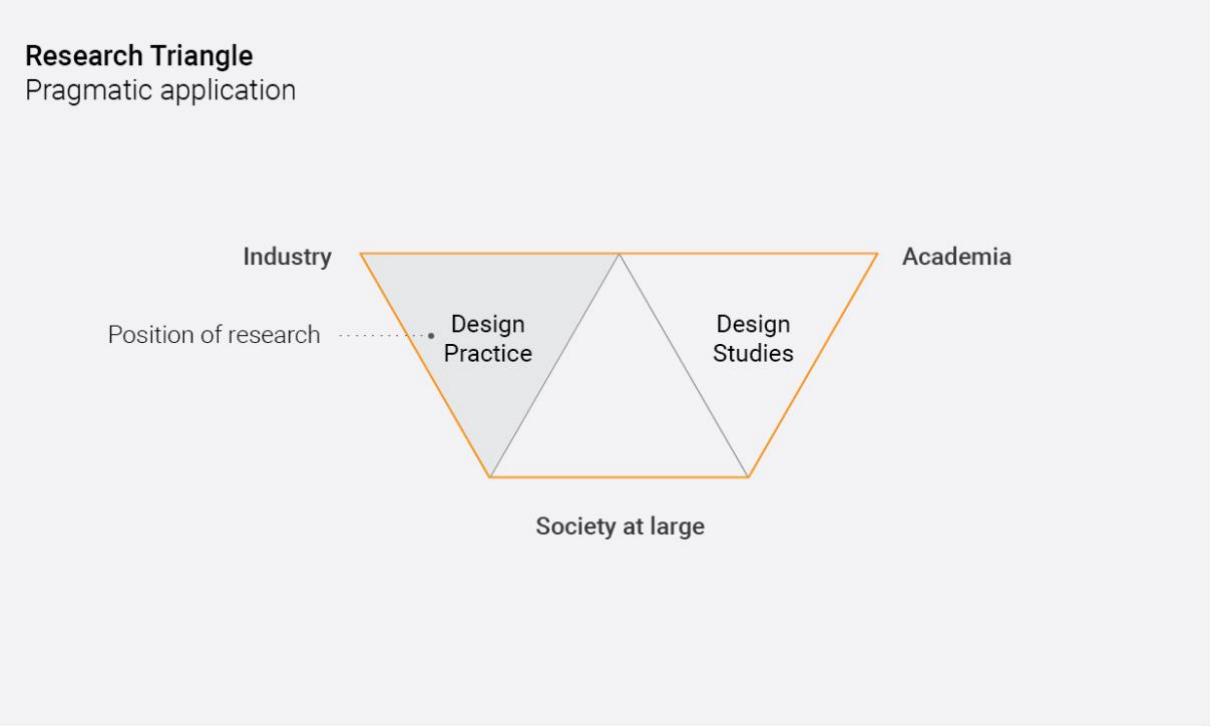

Figure 39. The modified interactive design research triangle.

This removal was done in the later phases of my research through discussion with my supervisor. Although the model is no longer a triangle, I decided not to further manipulate the basic form (Figure 39). This is because I consider this removal to be a modification of the triangle, not the development of a new model. Removing the *explorative* section of the

Triangle gave me a practical and precise model without any excess elements to distract from my research focus. To maintain the model's relevance for real-world research, the outer space of the Triangle containing industry, academia, and society was kept in place.

To remove an entire activity area of an established and recognised theoretical model may be perceived as a controversial act. However, my aim with removing the activity area was not to provoke or disrupt the Triangle. For me, it was a pragmatic decision based on reflections and a desire to further operationalise the Triangle for design practice.

As a note, the impact of the removal is that stakeholders in Halogen now uses this model as a framework for considerations of design activities, reflection and communication with clients and partners. This brings me over to discuss the quality and relevance of the research.

5.4 Quality of the research

The Research Council of Norway (2000) suggests that quality in research is related to three aspects (translated from Norwegian to English by Utne (2007):

- *Originality:* to what extent the research is novel and includes innovative use of theory and methods
- *Solidity:* to what extent the statements and conclusions in the research are well supported
- *Relevance:* to what extent the research is linked to professional development, or is practical and useful to society

The results published in this thesis are primarily based on three journal articles. Therefore, the quality of this research has been assessed through peer reviews. In the following sections I consider the quality of the research in general, considering all three articles.

5.4.1 Originality

This thesis is positioned in professional design practice concerned with design of safety-critical systems. As shown in section 3.1**,** research in this particular field is limited. Furthermore, research on the development of methods to support this field is even more limited. Other than my own, only one publication has been identified that addresses this problem. This paper, by Shorrock and Williams (2016), addresses the intended use and constraints of research-developed methods in HF. The authors outline three key constraints and suggest the implications of this and ways to improve the availability and actual use of HF methods in applied environments and practice. However, the paper only offers a superficial approach to developing and researching methods in practice. I therefore assert that the topic of this thesis is original.

The originality of this thesis can then be assessed by considering the use of research methods and strategies to accommodate the constraints of safety-critical systems in commercial projects, most notably the FFI project. The tactic of pragmatically adapting and combining methods from design and HF into analogue tools offered two main advantages. First, it demonstrated a method for accessing and understanding unfamiliar theories that reside in safety-critical systems. It also showed how these theories can be applied to design research in a designerly manner. Second, it demonstrated a practical way to collect and

review data relevant to a specific project in an economic and efficient manner that could be used in a field setting. Notably, combining SA theory with sketching and visual means proved to be an enjoyable process that also encouraged learning and reflection. Additionally, the visual outcome of these processes invited fellow researchers and practitioners to directly reflect on and critique the material. This established a process that contributed to both reducing bias and enhancing the analysis process.

I would also suggest that the expansion of the interaction design research triangle is an original facet of this research. This involved expanding the Triangle horizontally and vertically to deliberately loop between activity areas and disciplines. These loops, combined with the act of sketching preliminary creations, contributed to new discoveries in the industrial projects and my own research approaches. Eventually, the discoveries and reflections from these loops led to my decision to remove the *explorative* activity area from the Triangle. This resulted in a new pragmatic, operative research model for my field setting.

As an aside, this PhD research and the results of the SA concept design assessment tool have generated interest in the HF community in Norway. This interest focuses on two main topics: (1) the process of connecting design theory to HF theory to develop practical methods in a field setting, and (2) the SA concept design assessment tool developed through my research. As one HF specialist commented, there is currently no way to validate and verify the translation of analysis to design. He added that this makes the design tool highly interesting and important for the development of new safe, robust systems. This led to invitations to present my research at HF conferences and to teach design methodology as a guest lecturer at a university.

5.4.2 Solidity

Solidity is related to rigour. In this thesis, rigour is strongly shaped by the field setting and by my role as a researcher and practitioner. In 'Nature of Research,' Archer (1995) discusses how valid research is defined through a practitioner's actions. In addition to proposing the defining conditions of research in practice, he points out certain aspects that might help frame rigour in the space between practice and research. According to Archer, practical action can be used as a medium for conducting systematic inquiry to devise or test new imported information, ideas, or forms in order to generate communicable knowledge. The researcher performs specific actions in the real world to devise, test, or shed light upon something. This kind of specific behaviour can also be recognised in Fallman´s proactive role in research as design practice (Fallman, 2008). However, Archer argues that, in such circumstances, it is nearly impossible to conduct an interference-free, non-judgmental investigation. Further, such investigations are almost always dictated by the complexity of real-world situations. Thus, the findings only apply to the place, time, persons, and circumstances in which the activity took place. These conditions should be made clear and explicit. Archer further argues that it is both difficult and dangerous to generalise this kind of research findings. However, he goes on to suggest that these findings can nevertheless be extremely valuable and can produce insights which might otherwise never be obtained (Archer, 1995).

Although Archer draws on Action Research, he presents interesting and valuable arguments that I believe resonate with Fallman and Stolterman´s discussion on rigour in the research as

design practice approach. They point out that, in certain areas of design research, it is assumed that the quality of research results depends on a close relationship between rigour and quantitative approaches (Fallman & Stolterman, 2010). However, they argue that it is a common misunderstanding to assume that rigour increases with complex statistical models and controlled experiments. For example, my field setting, in which I observed a designer observing submarine operators crash dive the submarine we were in, was far from a controlled laboratory. In this setting and situation, I watched as a designer grabbed a railing with one hand to avoid falling while the other hand gripped the method iteration to keep from losing it. As a researcher, this provided me with a particular set of data that I assume would be difficult to recreate in a laboratory. However, due to the limited body of literature in this field, the setting also presented certain challenges. These mainly involved the challenge of framing my research, which took a qualitative but pragmatic approach, as rigorous. This was even more challenging since my research offers something to audiences in interaction design and HF.

In HF, rigour is generally defined to mean working somewhere between science and practice to achieve repeatable results in both controlled and real environments (Stanton et al., 2013). In interaction design research, on the other hand, Fallman and Stolterman (2010) suggest that qualitative approaches cannot in themselves be regarded as less rigorous. Here, the quality of research should be examined based on transparency, the systematic approach, and the clarity with which claims are presented (Fallman & Stolterman, 2010). Archer (1995) shares this understanding of rigour in design research, as do Zimmerman et al. (2007) in their model for interaction design research in HCI.

As described in chapter 4.5, the research in this thesis was done using a systematic approach based on the interaction design research triangle. I have sought to follow the recommendations of Creswell (2013), Goodman et al. (2011), and Kvale and Brinkman (2014) to systematically make research methods and approaches transparent and clear. A central activity in this process was describing my claims and chains of arguments that built on earlier research. Based on the recommendations of Archer (1995) and Fallman and Stolterman (2010) for rigour in the space between practice and research, the circumstances, place, time, and people involved in my study are described in sections 1.7, 4.6, 4.6.1, and 4.6.2. The knowledge claims and arguments have subsequently been shared through publications and public presentations. In addition, I have made an effort to make my research transparent and clear by identifying the limitations of each publication in section 4.11. However, as described in section 4.6.2 and 5.1, specific data, information, and research outcomes could not be made public. Nevertheless, I suggest that the research is still significant since the publications focus on the activities of method development and using those methods.

To clarify my claims, I have shared and discussed my interpretations and reflections with fellow researchers and practitioners. As described in section 4.10.2, all three publications were discussed and critiqued on the basis of how the research could help them explain and create in their everyday design work. I suggest that the clarity of the arguments presented here is one of the more important aspects of this thesis. By this I mean that if the claims and arguments are not clear to practitioners, then the quality of the research makes it less relevant than otherwise. After all, the practitioners are the ones who will ultimately apply the new knowledge, if it is relevant. As Fallman and Stolterman (2010) suggest, if the final

design makes sense and is useful, its rigour is less of an issue. I will consider this aspect in the next section.

5.4.3 Relevance

As described in section 2.2.6, a number of studies have shown that design methods developed in academic research are not applicable or relevant to design practice. This can become increasingly problematic when design practitioners' transition into the field of HF. As described in section 2.2.7, this is a domain which has traditionally been considered outside the field of design. However, a review of recent HF literature suggests that the HF community also struggles with methods that lack user focus and applicability to real-world practice (Shorrock & Williams, 2016).

As stated in section 3.1.1, it is reasonable to say that design methods for design practitioners and for HF practitioners lack the same two main components: first, applicability to real-world constraints in applied environments and, second, support for informed judgment and argumentation early in the design process. Based on the literature review, I propose that both HF and design research lack practice-based frameworks for understanding and developing methods for safety-critical systems. This represents a significant problem for practitioners employed to design safe, robust solutions. These designers are well aware of the potential consequences of a poor design and of its potential negative impacts on society at large. Given the recent transition of design practice into the design of safety-critical systems, it seems reasonable to suggest that design research has not yet had the time to develop appropriate methods for this emerging field.

As described in section 5.1, I have, in-situ, developed new design methods to support design practitioners at Halogen. These design methods focus on addressing the challenges of translating analysis to early concept designs in messy, real-world situations. The user-centric process of developing these design methods made it simpler to introduce practitioners to the methods and then train them to use them. Not only did the practitioners intimately learn the core of a method, they also became acquainted with unfamiliar HF theories through practice. Practitioners were asked to provide feedback and evaluation, allowing them to influence and contribute to the method development process. This proved to be central to giving the practitioners a sense of ownership and also to developing truly relevant methods. In this manner, an undesirable situation was transformed into a better one through design, which helped establish relevance of the specific methods and models for the practicing designers (Fallman & Stolterman, 2010). In pragmatism, such an outcome can be called pragmatic validity. As described in section 2.4.4, pragmatic validity rests on observations and interpretations that include a commitment to act on those interpretations. A knowledge claim is then validated through the effectiveness of these actions (Brinkmann & Kvale, 2014).

As described previously, the majority of the design methods developed in this research were used to develop a concept design for a submarine operations room. As a result, designers at Halogen are currently using the design methods to further develop the design solution for Kongsberg Defence and Aerospace. This work consists of designing the operations room to fit the design of the Thyssen Krupp 212CD submarine. However, the development process and life cycle of safety-critical systems last a long time. Testing and refinement can go on for

up to several years before a design is ready for the market. As described in section 4.6.1, when operational, a submarine and many other safety-critical systems have long life cycles that last up to three to four decades. This represents a challenge to validating the long-term effects of the design methods for applied environments developed in this research. Still, the observations made during the use of the SA concept design assessment tool had positive indications for final designs (Figure 40). Recently, observations were done during OPAS (operator assessment) tests of an air defence console design. The design method was shown to support designerly and SA-informed reflections on and judgments of the design and the operator's behaviour. These judgments later became arguments which the client´s production and marketing division used when introducing the system. Thus, based on Fallman and Stolterman (2010), this solution is also relevant for the industry because it led to safe and communicable solutions.

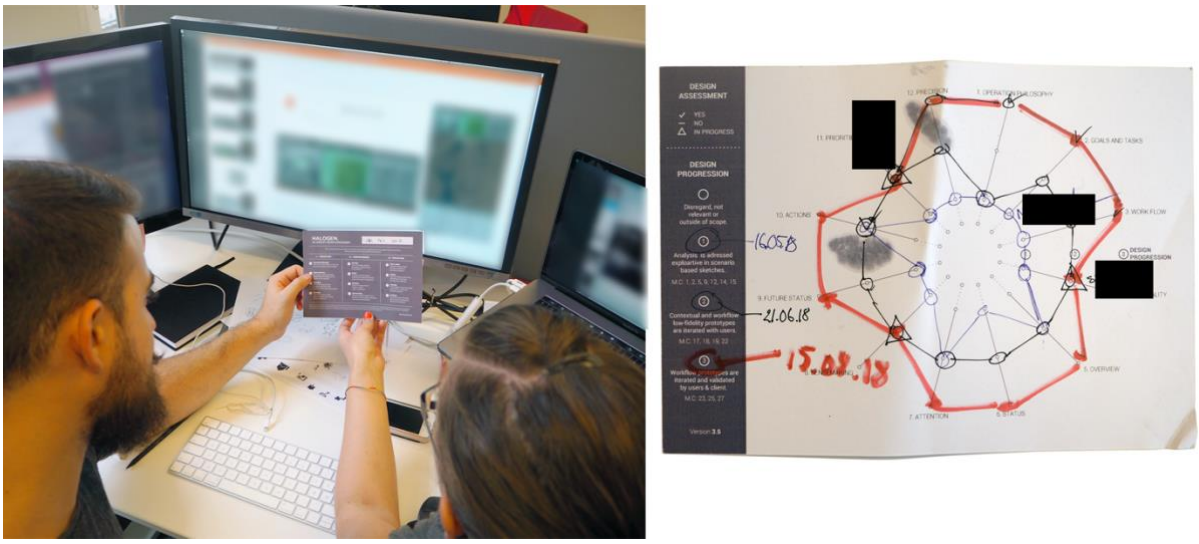

Figure 40. Design practitioners making final assessments based on the SA concept design tool for air surveillance design components. Photo credit: Jan Fredrik Schønheyder

The HDMC has further contributed to new projects at Halogen. Clients such as Equinor and the Kongsberg Group recognise that Halogen has its own design approach and methods for ensuring the integrity and documentation of the design process. Thus, based on the introduction of the HDMC at Halogen and the publication of my three articles, I would suggest that this thesis is timely and relevant for the interaction design research community, practicing designers, and society at large.

5.5 Summary

Overall, the results from the journal articles contrast with and expand on existing literature on how design methods are used by skilled professional design practitioners. These results answer the call for in-situ research made by scholars such as Gray et al. (2014), Goodman et al. (2011), and Stolterman (2008). The findings from these research processes additionally expand on and complement theoretical and strategical approaches to conducting in-situ research. Combined, the results provide a new understanding and new knowledge of how methods can be developed in the future to support professional design practice. However, there are not many design projects in safety-critical systems, and these projects last for long periods of time. This means that the potential sample for this area is small in scale,

restricting access to additional data on this topic. As a result, the research limitations described in 4.11 are central to understanding the research outcomes of this thesis.

During this research, the interaction design research triangle provided a practical, consistent platform which was used to frame and conduct activities and to communicate the work. The use of expanding loops enabled me as a PhD-fellow to systematically learn how to conduct and practice conducting academic research. I found it especially valuable to continuously reflect from two perspectives (practice and study) within the frame of pragmatism. As a result, my explicit understanding of my own research in relation to industry, academia, and society at large increased.

The next chapter presents the two main contributions of this thesis. These contributions result from the above-mentioned findings and the approach of surfacing a bridging theme.

6 MAIN CONTRIBUTIONS

By conducting research from a *design practice* approach, this thesis addresses the research questions and gaps described in chapter 3. Overall, it describes the problem as that most research-developed methods for interaction design lack applicability to and resonance with the real-world constraints found in everyday professional design practice. This thesis presents two main contributions which addresses this problem (Figure 41).

The first contribution addresses gap 2 – the lack of an understanding of current methods in design practice, as described in section 3.1.2. It introduces a framework to explain the status quo of method use and development in professional design practice. The material in contribution 1 has the potential to address gap 1 – the lack of safety-critical design methods, as described in section 3.1.1.

The second contribution addresses gap 3 – the disconnect between practitioners and researchers described in section 3.1.3. Contribution 2 is an overarching theme: I propose a model that could improve the relationship between research and practice. The model has the potential to establish a shared pragmatic vocabulary that design researchers and design practitioners would both understand.

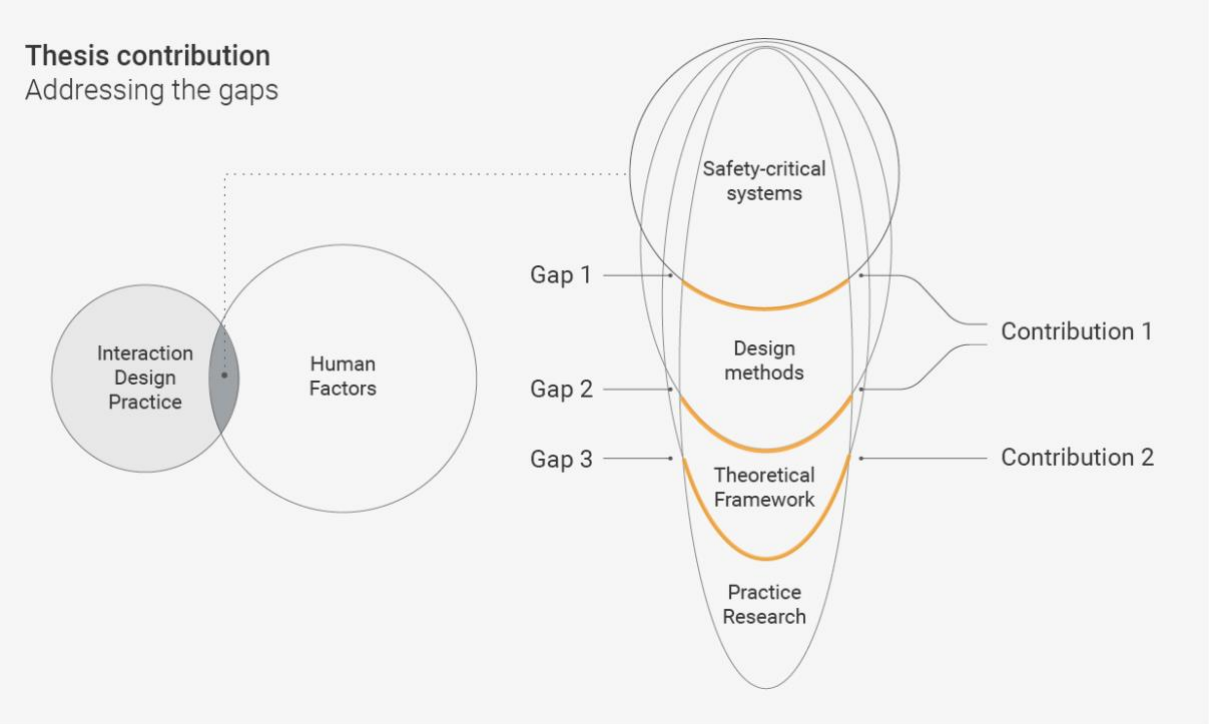

Figure 41. Research gaps and position of the contributions from my research.

6.1 Contribution 1: Pragmatic and disciplined ways

The aim of this research was to improve design practice in the context of safety-critical systems. My focus was improving design methods through a *design practice* approach to research. However, bringing about such a transformation requires a clear understanding of the current situation (Fallman & Stolterman, 2010). Thus, the status quo needed to be

defined before a transformation could begin. For my industrial PhD, this was done in the context of Halogen.

6.1.1 Understanding the current situation

As stated in chapter 3, design practice in the context of safety-critical systems is a fairly new, emerging field. So, it is natural to assume that design research has not yet had the time to develop frameworks and methods to support design practice. Thus, a central problem in my research was the lack of frameworks and literature to describe the current status of design practice in the context of safety-critical systems.

There were two specific issues. First, there is a lack of frameworks to describe how methods are perceived, used, and developed in the design of safety-critical systems. Second, there is a lack of frameworks to describe the components, fields, and disciplines that design practitioners encounter (outside the design domain) in the design of safety-critical systems. Although there is some literature on maritime design (Lurås, Lützhöft, & Sevaldson, 2015; Lurås & Nordby, 2014), it does not address real-world design practice.

As described in section 2.2.4, without an established framework to describe the current status, it is difficult to apply Schön´s (1983) ideas of *problem setting* and *problem solving* to the area of designing safety-critical systems. These ideas are considered fundamental aspects of design; Schön points out that understanding *what* should be built is as important as understanding *how* to build it. I would suggest that Schön´s concepts of problem *setting* and *solving* can be transferred to this thesis.

I first accepted Schön's and Fallman and Stolterman's concepts for understanding a situation. Then I committed to, first, establishing a framework to describe the status quo. However, understanding this is was not straightforward. Due to the confidential nature of safety-critical systems and design practice, this particular form of research required access and a level of trust. Meaning my role as a researcher had to be accepted as part of a design team. In the interest of time and because of the scope of my industrial PhD project, I conducted this research at Halogen (where I was already an employee).

6.1.2 Standing between scientific and designerly traditions

The reason that status quo was important circles back to the pragmatic concept of *primacy of practice* (Hickman & Alexander, 2009). In short, this concept assumes that actions, thoughts, and objects must be understood as part of a contextual whole before one can judge and act in an unfamiliar situation.

For this thesis, that situation involved the transition of designers into an unfamiliar domain. The HF community is considered the prime authority in the domain of safety-critical systems (Lurås et al., 2015). As a scientific discipline, the field of HF has a long tradition and a body of research that are mostly unfamiliar to interaction design practitioners. As a result, design practitioners lack knowledge of how safety-critical systems are developed and also the vocabulary to talk about these systems (Lurås et al., 2015). Lurås et al. makes a significant contribution by pointing out this transition. However, I will suggest that, in this situation, it is equally important for the HF community to gain a *designerly* vocabulary and understanding. By this, I mainly mean Cross´s (2006) distinction between designerly approaches to thinking,

acting, and knowing and scientific and scholarly ways of knowing. Consequently, a shared framework that describes the status quo from a design perspective must be developed to reduce the disciplinary barrier between design and HF; this is as important as the need for designers to learn to communicate with HF experts.

A framework encompassing both HF and design practice would be an important pursuit for future research and method development. Such a framework could positively affect, not only design research, but also design practitioners' own understanding of designing in a high-risk domain.

6.1.3 Establishing pragmatic and disciplined ways

Based on my research findings, I have developed a framework to illustrate the status quo of method development in design practice (Figure 42). This framework includes aspects of four components: the theoretical foundations of interaction design and HF, the cyclic evolution model, and the IGM method. These components are connected by the design practitioners' pragmatic, disciplined approach to using and developing design methods in the context of safety-critical systems.

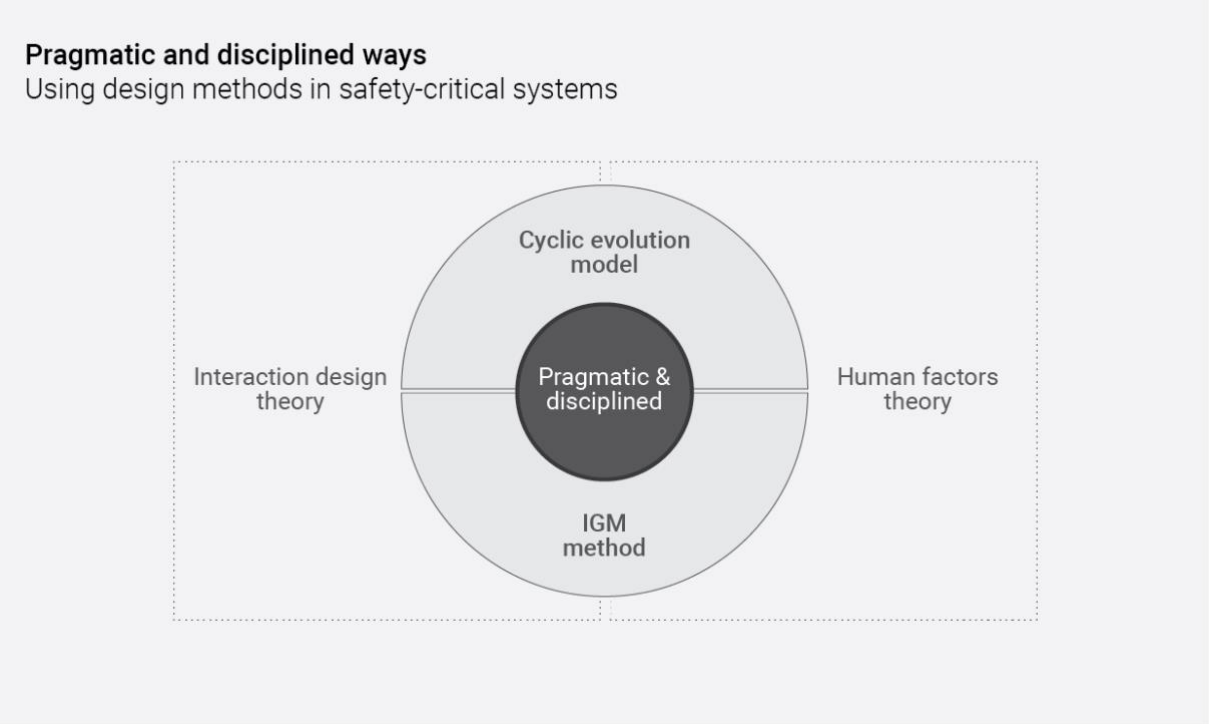

Figure 42. The status quo of method development and use in design practice.

Positioned on the top half of the model, the Cyclic evolution model is laid across the theoretical foundations to connect interaction design and HF. The model was developed through my in-situ study and can be characterised as a descriptive framework. This model accurately describes how design practitioners use design methods in the context of safety-critical systems (Schønheyder & Nordby, 2018). It offers an in-depth account – from an insider's perspective – of how methods are pragmatically developed and adapted to fit the situation at hand in real-world contexts. Through a conscious, systematic approach, methods evolve through cycles of use, varying from a project to the next.

The status quo can be understood in more depth by also laying across the IGM method over interaction design and HF. When this is done, the role of designerly ways of knowing and doing sheds further light on how design practitioners use a particular method in unfamiliar domains and situations (Schønheyder, forthcoming). In such situations, designerly skills and techniques such as sketching, visualisation, and reflection are employed to make sense of wicked problems and gain new knowledge. The outcomes of these activities are then used as design input and arguments in discussions with client stakeholders and legislative authorities.

Combined, the components of this model illustrate an emerging field where the scarcity of existing literature and guidelines inspires pragmatic, designerly approaches to using and developing methods. These approaches incorporate a highly developed, disciplined, conscious approach to designing robust, safe solutions. The emphasis is on solving the problem at hand to generate input and arguments for a particular design. However, there are no formalised methodologies or frameworks documenting this process. At Halogen, these approaches are mostly tacit and are only made explicit through mentor–apprentice relationships. Thus, personal worldviews and experience have the potential to significantly influence the development and use of methods.

6.1.4 Reflections on pragmatic and disciplined ways

The pragmatic, disciplined approach sheds light on two interesting aspects of method development in practice. First, according to the existing literature, most design practitioners are not concerned with or interested in rigour or intentional development processes (Gray, 2016; Rogers, 2005). However, the status quo at Halogen opposes this. Instead, disciplined, conscious approaches are learned and performed in this practice. To compensate for real-world constraints and unfamiliar situations, the disciplined approach is accompanied by pragmatic, designerly ways of doing and knowing. I will suggest that this habitual way of working represents new opportunities for method development that would be of interest to the design research community. As Stolterman suggests: 'In order to change design practice, we need more research that examines, uncovers, analyzes, and interprets what interaction designers are already doing' (2008, p. 62).

A question of paradox

The status quo sheds light on another interesting aspect of method development and the use of methods in practice. From a scientific perspective, a pragmatic, designerly approach may be perceived as a paradox when developing and using methods for safety-critical systems. However, from a pragmatic perspective, it may make sense. Although this field deals with high-risk environments with serious potential consequences, the practical application of a method overrules scientific or established methods. This means that a method that can provide scientific rigour and validation but fails to provide usable results for a given situation will be ignored and discarded. This is the primacy of practice principle in action; practice takes precedence over doctrines (Dalsgaard, 2014).

Between the designerly and the scientific

Stolterman (2008) argues that, in the process of creating a design, skilled designers tackle complexity in a designerly, disciplined and rigorous way. However, he points out that a designerly way of acting has not been developed through intellectual discourse the way

scientific traditions have been. Although this discourse has progressed in the design and HCI communities, I presume it is still an unfamiliar concept in HF. As a result, this aspect of the status quo in design practice may present interesting questions for the HF community if it is to understand the role of interaction design practice.

A way forward for design methods in safety-critical systems

As discussed in Gap 1 – The lack of safety-critical design methods (3.1.1), there is a lack of formalised design methods that is relevant and applicable everyday interaction design practice. Here, the status quo establishes a theoretical framework that presents a way forward for developing practice relevant design methods. This can additionally be achieved by overlaying the rigour and relevance model from article 3 (5.2.3) which introduces a conceptual framework for method development in professional design practice.

In my own research, the approach of overlaying method development over the pragmatic and designerly ways framework, enabled me to develop the SA concept design assessment tool, as described in article 3. The tool further addresses Gap 1 by supporting practitioners with a tool to translate analysis to early concept designs of safety-critical systems.

However, for researchers to access professional design practice can be seen as a barrier for method development. Particularly those practices employed with client sensitive information and systems prone for industrial espionage. For both researchers and practitioners, this would require trust and expectation management for a potential long-term commitment. Consequently, the actual method development process may best suit method developers employed within a practice. Although this may limit the use of the framework, the combined frameworks of pragmatic and designerly ways and the rigour and relevance model still stand open for critique to further expand the understanding of design methods in practice.

6.2 Contribution 2: The space between design practitioners and researchers

I have now described the current status along with a model that may present new possibilities for future practice-based method development. The second contribution of this thesis I present a reflection on improving the disconnect between researchers and practitioners. Using triangulation and surface sequencing as described in 4.10.2, I have created a model of a shared framework where researchers and practitioners can facilitate reflection, discussions, and the development of a common vocabulary.

6.2.1 Academic conception of practice

The definition of the problem in chapter 3 mentions a third gap: the gap between practitioners and researchers concerning the development of methods that are relevant for practice. Central issues in this gap include the lack of applicable research-developed design methods (Goodman et al., 2011) and practitioners' lack of rigorous use and knowledge of methods (Rogers, 2005). As a result, researchers view practitioners as uninformed, while practitioners view researchers as out of touch with reality (Gray et al., 2014). A similar relationship can be observed in HF in statements like 'practice is lagging behind research' and 'research fail to provide usable methods' (Shorrock & Williams, 2016, p. 470).

This disconnect between researchers and practitioners concerning method development is, in many ways, related to an ongoing debate over theory and practice within the HCI and interaction design research community. This debate has generated frameworks such as the 'bubble-up and trickle down' (Gray et al., 2014) model for interaction design research within HCI research (Zimmerman et al., 2007) and bridging concepts (Dalsgaard & Dindler, 2014). Perhaps the most notable contribution to this discussion is the interaction design research triangle (Fallman, 2008).

However, according to Gray (2016), communication between the research and practice communities is still unidirectional. Drawing on studies by Goodman, Roedl, and Stolterman and on his own work, Gray argues that this unidirectionality exists due to the 'projected practice community.' By this he means that most academic researchers draw from information based on an academic conception of practice, not how practitioners actually work. Thus, it is natural to presume that there are currently no adequate frameworks to improve the relationship between research and practice in the context of everyday work.

6.2.2 A unidirectional relationship

A primary concern of Gray, Stolterman, and Siegel (2014) is that the unidirectional relationship between research and practice in design strongly degrades each side's understanding of the other's expertise and knowledge. They also consider it a serious problem that very little research examines how practice may positively influence research. Recently, Gray (2016) argued that the lack of relationship and in-depth knowledge of design practice may ultimately implicate how design research understand what it means to be an interaction design practitioner.

In my research on safety-critical systems, I propose that this unidirectional relationship is an issue, not only for design practitioners and design researchers, but also in relation to HF researchers. The design managers at Halogen have stated that they need the HF community to provide a theoretical foundation for the development of original methods (Schønheyder

& Nordby, 2018). This attitude towards research contrasts with previous descriptions of practitioners' view of research in design literature. It also highlights an important aspect addressed by Dalsgaard and Dindler (2014) related to the gap between theory and practice in HCI.

On the topic of developing theories out of design practice, Dalsgaard and Dindler (2014) state that one of the persistent challenges for interaction design researchers is the gap between theory and specific design situations. They propose that theories are abstract by nature since they must fit a wide range of settings. As a consequence, it can be difficult to translate them to a particular design context, much less to operationalise them. Dalsgaard and Dindler (2014) argue that articulation and facilitation must take place to identify what regards as relevant theory for practice.

In my own research, I experienced the challenge of translating theory into a particular design context. Most notably, the process of translating SA theory into practical heuristics for design practitioners, as described in article 3. In this case, it was especially important that legislative authorities could understand the process of translation. After doing this myself, I consider Dalsgaard and Dindler´s argument a timely and important one supporting a closer relationship between research and practice.

6.2.3 Establishing a shared space between design practitioners and researchers

During my research, I arranged for researchers and practitioners to meet and interact over specific real-world problems. Through this process, I identified some factors that may help improve the relationship between researchers and practitioners. I further reflected on what I learned and made it explicit through the triangulation and surface sequence (See 4.10.2). These interlinked factors are a shared visual framework, a shared visual vocabulary, and iterative loops and tension.

The first factor is a framework that is shared by researchers and practitioners. I found that the interaction design research triangle provided a clear frame that designers could gather around. To make this framework accessible, a large copy of my model of the Triangle was printed as a tool for discussions. This model including industry, academia, and society at large in the outer space of the triangle, which allowed commercial and academic impacts of the work to be included in the discussion. Pragmatism was then added as an outer dimension to the triangle. This was done to frame discussions in a real-world context and to facilitate articulations that both parties could understand. My hypothesis was that pragmatism would bring certain core worldviews, which are implicitly understood by practice and which could be explicitly understood and translated by research, into the discussions. In this way, pragmatism can be seen as equally important for both research and practice.

Based on my study on the use of design methods in Halogen, I found it important to facilitate practitioners' tacit knowledge and designerly ways of working. I therefore selected sketching as a tool for interacting with researchers. According to Buxton (2007), sketching a natural activity for designers that can quickly build a visual vocabulary. So, in combination with pragmatism, sketching was employed as a means for reflection and articulation in interactions between researchers and practitioners. These sketches were then located

spatially on the framework map so they could be discussed. This method encouraged the incorporation of Schön´s (1983) idea of reflection with the situation. As a result, a shared vocabulary was gradually built and made explicit through visual images placed on the framework.

A significant factor in improving the relationship between researchers and practitioners in my research was facilitating iterative loops between the activity areas of *practice* and *studies* through the pragmatic dimension. Although the *explorative* activity area was present, it was never used. However, I observed that these iterative loops from *practice* to *studies* through the pragmatic dimension encouraged the participants to view a problem or an occurrence through different perspectives. I could then use pragmaticism to facilitate discussions on concepts such as practicality, experience, situation, and validity within the contextual whole. To further frame and guide articulations, I added tension to the pragmatic dimension by adding the words *create* and *explain* on opposite sides. This step was inspired by Fallman and was designed to point out and articulate some of the differences in worldviews between practice and research (Fallman, 2008). However, because this tension was framed in a pragmatic, real-world context, discussions quickly focused on applicability, relevance, and needs in particular situations. Significantly, helped researchers and practitioners agree with each other's perspectives and also challenge their own worldviews through pragmatic arguments.

However, based on my own research findings, I have reason to suspect that the presence of the *explorative* activity area in the Triangle can contribute to misunderstandings and draw attention away from the topic at hand. Therefore, based on a pragmatic perspective and my own research, a simplified framework can be created by removing the *explorative* dimension from the model. In this new version, the loops and tension are clearly framed in the context of commercial real-world practice.

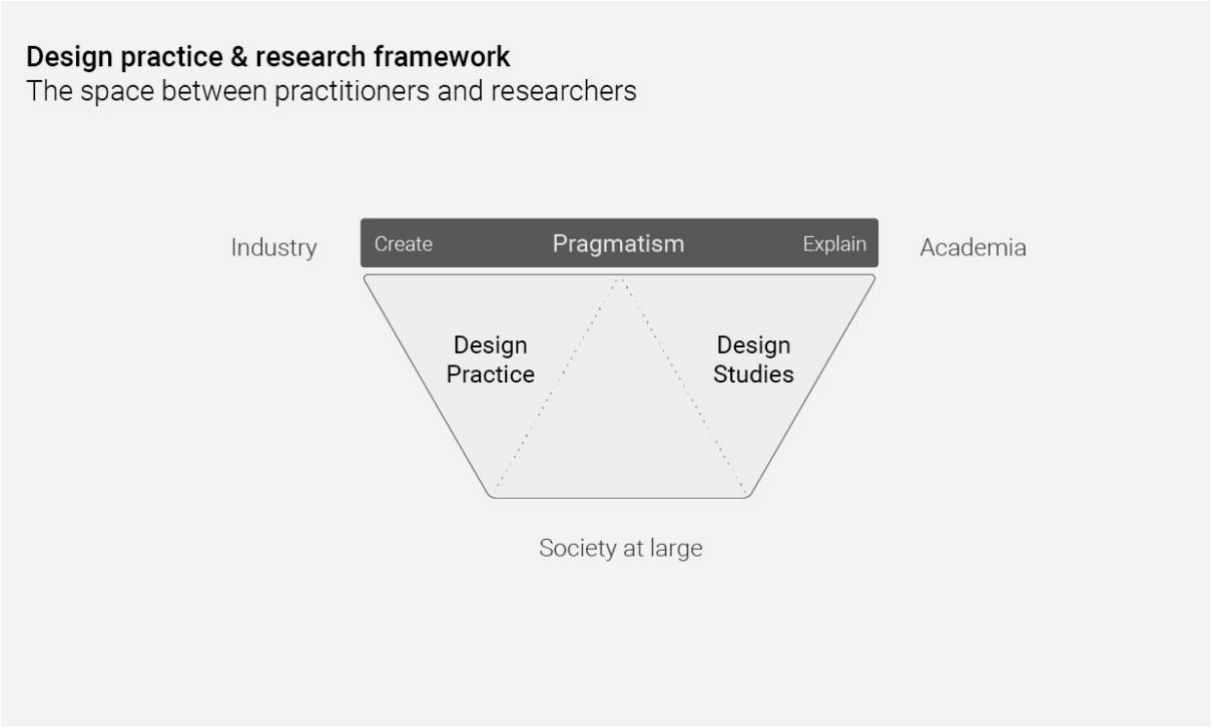

Figure 43. A framework for improving the relationship between practitioners and researchers.

This results in a *practice and research framework* (Figure 43) that combines a modified research triangle with a pragmatic dimension and added tension to highlight contrasting worldviews. The outer space of the framework grounds it in a real-world context where industry, academia, and society at large can be impacted by a design. This model could provide a theoretical framework for improving the relationship between researchers and practitioners. Further, because it employs a visual, pragmatic vocabulary, the model allows for validity judgements and can support the need to take action. Thus, guided by the primacy of practice principle, new knowledge can be generated from this framework (Worren et al., 2002).

6.2.4 Reflections on a shared space for improvement

As a result of the simplified Triangle, I will now further reflect on the possible influence of this framework on the researcher–practitioner relationship and on the framework's implications for that relationship.

Friedman (2003) argues that design failures is often a result of gaps in knowledge and preparation in the design process. He goes on by claiming that it is here that research and theory play a role (Friedman, 2003 p. 7). Drawing on Pye (1978), Cross (2006) on the other hand argues that invention comes before theory. Here, Cross (2006) explains that a designer´s understanding of a design process is usually ahead of the world. This means that the act of "doing and making" leads to science, not vice versa. I believe that such a statement clearly resonates with the primacy of practice principle where theories are formed in relation to specific situations (Hickman & Alexander, 2009). Further, my interpretation of Friedman and Cross´s arguments indicate the need to position both practitioner and researcher together and in-situ with the doing and making. Thus, providing an opportunity to identify and understand both the inventions and the failures of design. Here, I would suggest that the simplified Triangle may serve as such an in-situ framework between practice and theory.

An operative framework

Recently, there have been other attempts to influence the relationship between research and practice in design. Redström´s recent book *Making Design Theory* (2017) introduces a tactic called *parallels.* The aim here is to reduce the gap between designing and theoretical descriptions. In its most straightforward form, his proposition is to use existing research frameworks to create an overall structure. Then – often in retrospect – an existing design practice is selected and a reflective layer is added on top of it. While this approach does not automatically involve significant theoretical changes to practice, it may help bring practice and research together into one overall project (Redström, 2017). In many ways, Redström´s and my approach share a common structure. Both approaches seek to employ existing theoretical frameworks and to reflect on existing design practice. However, in Redsröm´s approach, this is primarily performed in retrospect, meaning that a set of design projects is later used as the basis of a research project. In my case, the reflection was done visually, collaboratively, and simultaneously by both researchers and practitioners in real time. Thus, my practice and research framework focus on a more operative approach to understand the

design process. However, like Redström's parallels, my introduction of a theoretical framework and a reflective layer can offer a promising starting point to improving the relationship between practice and research.

For researchers doing in-situ research, an operative framework that enables sketching and creating visual representations may additionally shed new light on *what works* in theory and practice. Based on the primacy of practice principle – that is, the contextual whole – images can become tools to guide actions and help designers reach goals. Subsequently, pragmatic validity can be verified through the symbolic representation of concepts and relationships and the simplification of complex information (Worren et al., 2002). Worren et al (2002) stress the possibility of bias due to self-assessment and direct user feedback. However, I propose that loops of reflection and tension shared between researchers and practitioners can reduce such bias. Thus, this framework may contribute to a better understanding of the relationship between visual images and the concept of validity in pragmatism.

Implementation through practical, relevant outcomes

To introduce and implement this framework, I would propose that it should ensure a practical, valuable incentive for practitioners. This is necessary because most design practitioners have limited time outside of contractual and client obligations. Consequently, research activities should occur in relation to a commissioned project. Here, I would suggest that the translation of theory to a particular design situation presents an interesting possibility, especially considering the role of interaction designers in the field of safety-critical systems. As Dalsgaard and Dindler (2014) discuss, research topics in interaction design and HCI are under constant development. This stresses the need for ongoing reflections on how these developments challenge theories and how theories can be employed to understand these new developments (Dalsgaard & Dindler, 2014).

In the case of safety-critical systems, this would also involve translating unfamiliar theories for a particular environment, technology, and even laws and regulations. Drawing on my own research on translating SA theory into design practice. Such a translation should strive for three outcomes: (1) to be understood and relevant for practitioners, (2) to be applicable to designerly ways, and (3) to be understood by legislative authorities. I presume that researchers would perceive this kind of research as practical and valuable and would be motivated to participate in it.

Overall, the practice and research framework can take the form of an operational model that can be employed in existing design practice where time and resources are limited. Imbedded in practice, the framework can serve as a shared space for researchers and practitioners working on short-term qualitative research projects or as a foundation for informal discussions. It thus provides a flexible and operative framework for the unforeseen situations and wicked problems that may occur in everyday practice.

Reflections on transferability

The practice and research framework may also provide new opportunities for certain fields involving practitioners and researches, such as law and business. To expand on the translation of theory into practice, I would suggest that this framework could also offer value to the field of medicine, especially the nursing and paramedic communities. These are

professions that practice in critical real-world situations with potentially severe consequences for life and health (Miller-Keane, 2005).

Similarly to the design and HF communities, there is a widely debated theory-practice gap in nursing (Rolfe, 2001). What I find interesting is that Schön´s concepts for knowing and reflection-in-action are central topics in some of these debates (Comer, 2016). I would suggest that, with minor adjustments, my framework could be used to establish a common space for discussion and knowledge exchange between practicing nurses and clinical researchers. However, such a transference should be further explored.

6.2.5 Limitations of the framework

Although this framework could provide value for in-situ real-world research, its use and application may be limited in other research contexts. The framework is simple and focused, which could make it unsuitable for long-term academic research in controlled environments. Research projects that require a wider scope, such as discursive and explorative approaches and historical and theoretical examinations may benefit from other theoretical frameworks provided by scholars such as Cross (1999), Frayling (1993), and Zimmerman (2007).

I will suggest that the practice and research framework is a specialised approach to building and improving the relationship between practitioners and researchers in the context of professional design practice. Through a shared pragmatic framework and vocabulary, tacit knowledge can be articulated visually and through the tension of switching between creating and explaining. In this way, wariness towards the other community and satisfaction in one's own community can be challenged and balanced in an equal framework.

6.3 Summary of contributions

I have presented two main contributions that address problems and gaps related to the use and development of design methods for professional design practice focusing on safety-critical systems. First, a framework which describes the pragmatic and disciplined ways design practitioners in Halogen employ methods in an unfamiliar design context. Second, I introduce a framework for design practitioners and researchers to meet on an operational level in the space between practice and theory. Combined the two contributions provide new frameworks and extend knowledge that may improve the relevance and integrity of methods used in design of safety-critical systems.

7 MAIN CONCLUSION

Three years of research in the space between academia and practice form the foundation for this summary. The focus of my research is motivated by my personal experience of ten years as a practitioner in industrial and interaction design. At the core of this focus is the effort to develop safe, robust methods to support the design of safety-critical systems. As an industrial PhD student, I have conducted in-situ research at the Norwegian design company Halogen. My work is situated in the *design practice* area of the Interaction design research triangle. I was involved in real-world design projects, most notably the concept development of a submarine operation room for the Norwegian Defence Research Establishment. The research reported in this thesis has been engaged in the challenges and constraints of everyday real-world interaction design practice. The *space between* could be regarded as central topic in this thesis. This includes the space between research and design practice, the space between scientific and designerly traditions, and the space between analysis and concept design. Consequently, the overarching theme in this thesis is the development of a practical platform for translation in the space between domains, traditions, and methods.

The main contribution of this thesis are three journal articles in which the use and development of design methods in the context of professional design practice are central topics. The thesis also contributes a theoretical framework that weaves these journal articles together to position and explain the current situation of practitioners' use of design methods in the design of safety-critical systems. The thesis also introduces a practical model aimed at improving the relationship between design practitioners and researchers. Combined, its contributions suggest that the potential impacts of this research may extend out from practice over to academia and pragmatism (Figure 44).

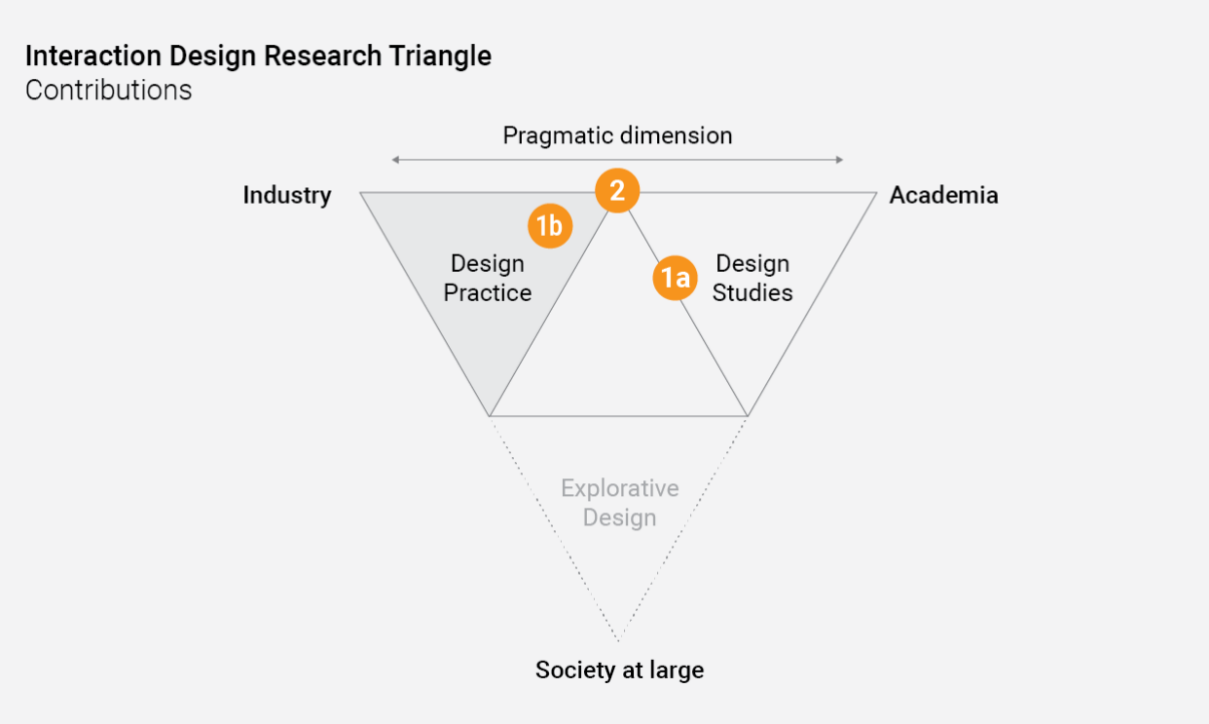

Figure 44. The position of the contributions of this thesis.

Contribution 1 (1a) describes the present status and builds and expands on the existing literature addressing in-situ research on design practice. This contribution introduces a generalised framework to explain how design methods are used to tackle unfamiliar situations and wicked problems in safety-critical systems. Since this is an emerging field, unfamiliar theories and scientific traditions may present new situations that might require exploration of non-traditional and pragmatic approaches. I will suggest that this framework may become a foundation for such explorations in developing practice relevant design methods and the field of interaction design in safety-critical systems (1b).

The second contribution is the *design practice and researcher framework* (2). I propose that this framework may help operationalise and improve the relationship between practitioners and researchers. This relationship is becoming increasingly important to the development of safe and robust designs for safety-critical systems. An improved relationship between theory and practice could also help establish interaction design practice and research as a field within safety-critical systems and other highly complex environments. As a long-term goal, this contribution may positively impact society at large by minimising the risk of accidents that may harm humans, the environment, or the economy.

In analysing the results of this study, I mainly drew on methods and approaches that are accepted and recognised in both interaction design research and HCI. In particular, the use of triangulation let me compensate for inherent weaknesses and build a more complete picture of real-world problems. In connecting the study to pragmatism, I gained a deeper understanding of method development for professional design practice, particularly in the context of constraints and challenges in everyday practice. The main insights are summarised in the following sections with reference to the three initial research questions:

1. How can professional designers' use of design methods be explained?
2. How can design methods be developed to support practice?
3. How can a design method be consistently evaluated in practice?

7.1 Research question 1

The first research question concerns understanding how professional designers use design methods. To answer the question, I present the pragmatic and disciplined ways model to explain how professional design practitioners work in pragmatic and disciplined ways in an unfamiliar field (Figure 45). The material in the model provides a theoretical framework that establishes a background to interaction design practice and human factors, and moves to a current explanation on how design methods are used in the context of safety-critical systems. Through in-situ research in a design practice, the material in the model further explains central methodological aspects of sketching and visualisation as means to tackle wicked problems and understanding the contextual whole of a situation.

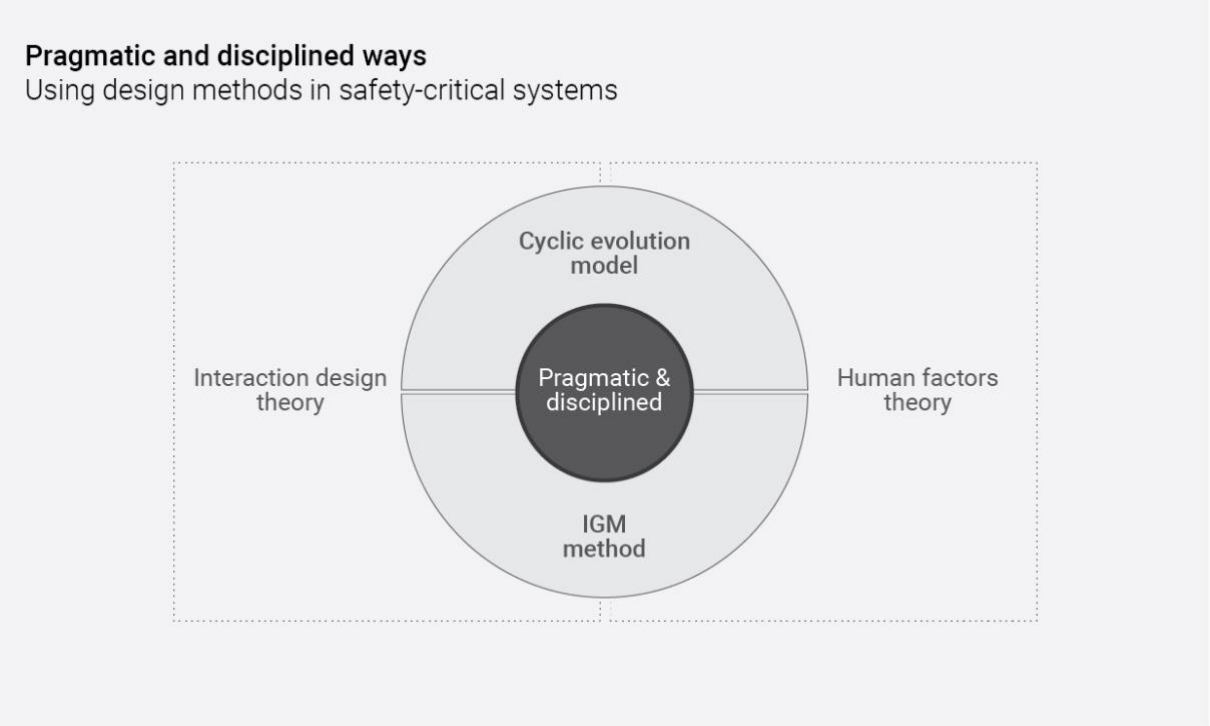

Figure 45. How professional designers use design methods in the design of safety-critical systems.

Although the model builds on existing literature, it also contrasts significantly with the current understanding of method use and development in professional design practice. The main finding here is that practitioners in this study has a conscious, systematic and pragmatic approach to using and developing methods. This explanation is presented from an insider's perspective and shows the entire life cycle and use of methods rather than centring on an academic conception of practice. As a result, the model explains in detail all the phases and drivers that shape and evolve design methods, from conception and selection through its use and transition into new projects. The model also sheds light on how and why certain methods are discarded. This model can therefore be seen as a framework for researchers that focus on the essential aspects of methods and on a method's relevance for practice.

7.2 Research question 2

The second research question addresses how design methods can be developed to support design practice. To answer this question, I introduce the rigour and relevance model (Figure 46). This model is designed to support the rigorous development of a method that has been generated in practice. The goal of the model is to introduce rigour while maintaining the method's relevance to practice. The model thus addresses two concerns found in the literature. The first concern is that most research-developed methods have no relevance to design practice (Gray et al., 2014). The second is that most design practitioners develop their own methods without training in scientific rigour (Rogers, 2005). Therefore, there is a need for design methods that can be used in the space between designerly and scientific traditions, such as the safety-critical systems domain.

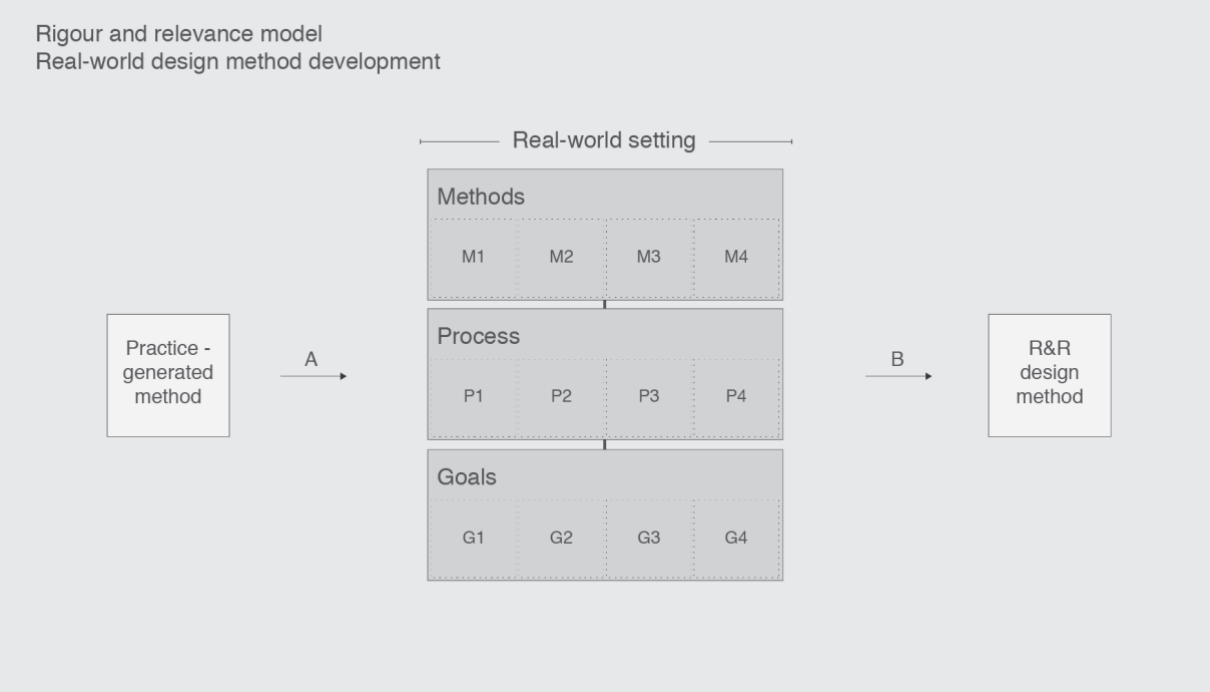

Figure 46. The conceptual framework of the rigour and relevance model.

This model includes twelve concepts that address methods for development, the process of development, and goals for the development. The 12 concepts are designed to be performed in a user-centric process within the real-world setting of a practice. This process incorporates user research and iterative user testing in the context of a working environment. This model's emphasis on user-centric concepts makes it fairly unique, according to the current literature, which reports that such approaches are lacking in the design research community (Dickson & Stolterman, 2016). Training users on methods and implementing those methods into a practice are significant components of this framework. In this way, the framework allows relevance and ownership to be developed and improved through actual needs, rather than conceptions of needs.

7.3 Research question 3

The third research question addresses how a design method can be consistently evaluated in design practice. I will use the pragmatic evaluation model to answer this question (Figure 47). The model was developed to consistently evaluate the relevance and impact of a design method in design practice. It allows a method to be evaluated based on explanatory approaches and theoretical principles. Heuristics and established theoretical principles are used to evaluate the method's relevance and the impact of its use. In this manner, a method can pragmatically evolve by remaining relevant to a situation, discuss skillsets and knowledge among designers. This may allow designers to independently navigate the use of a method in real-world design projects.

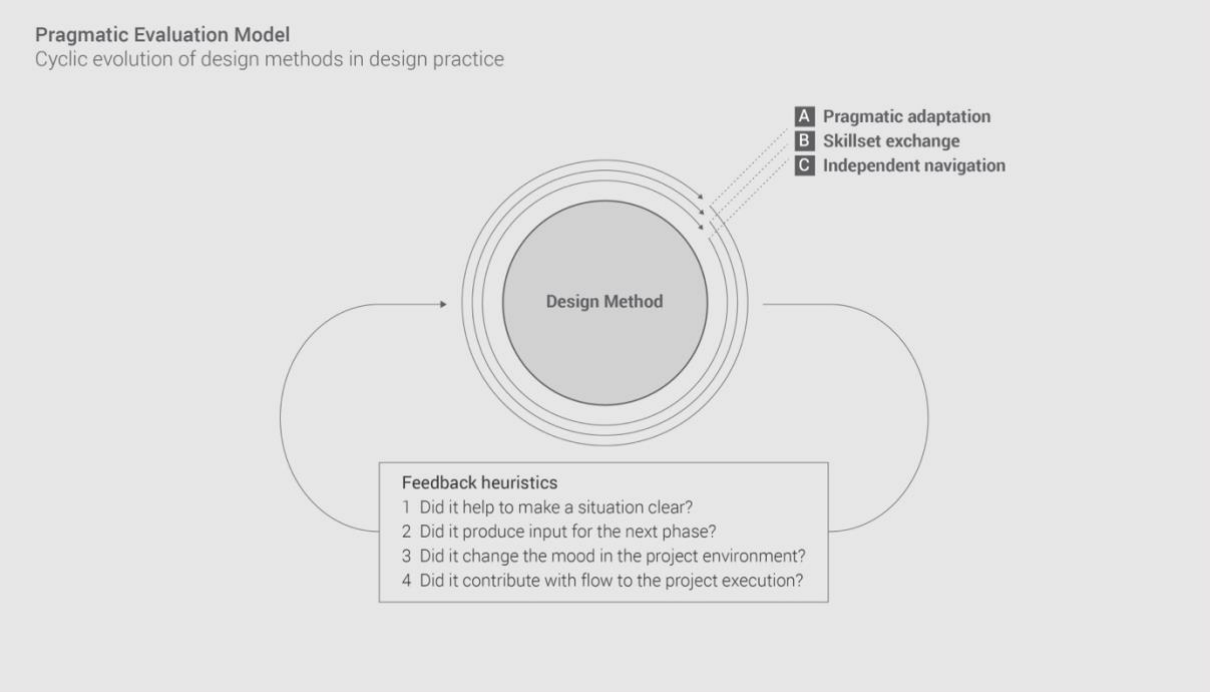

Figure 47. How a method can be consistently evaluated in design practice.

The primacy of practice principle is central to this model. This means that practice takes precedence over formalised methods. A core assumption in pragmatism is that judgments and actions should be considered on the basis of the contextual whole (Bacon, 2013). Thus, the model allows methods to be adapted or removed to fit the situation at hand. Drawing on my own experience, I have reason to assume that this principle has the potential to generate an explicit understanding of methods. As a result, this model may provide a new understanding of methods in practice for both researchers and professional design practitioners.

Since this model combines the results of an in-situ study with established theoretical concepts, I would argue that it is both theoretically and empirically grounded. This would indicate that the model is a generalised framework that is valuable in practice as well as theory.

7.4 Further work

I would suggest that the space between practice and research in the context of safety-critical systems represents several opportunities for further research. However, two particular topics are of interest to me for further research.

7.4.1 Long-term use of the SA concept design assessment tool

As an extension to the method development process in practice (article 3), I am interested in examining the long-term use and impact of the SA concept design assessment tool. The final design outcomes would be of particular interest in such a study. Two questions could be addressed: First, in what way does the tool help impact the design process? Second, in what way does the tool help lead to an improved solution for the end user?

Findings from such a study could also help define the further implications of the rigour and relevance model. In light of the pragmatic evaluation model, studying the tool's applicability, relevance, and design judgment over time may shed new light on how methods are used in practice.

7.4.2 How does SA theory impact practice?

As my study progressed, I noticed that the participating designers gradually adapted SA theory to their designerly ways of doing and knowing. This could primarily be observed in a number of design activities, such as how they planned workshops, asked questions, observed users, performed analysis, generated ideas, and reflected on design concepts. These observations contrast with existing studies proposing that design practitioners struggle to apply extensive theoretical frameworks (Rogers, 2005).

As a researcher and practitioner, I would be interested in investigating how SA theory impacts design practitioners. As a first step in this pursuit, I have begun to offer introductory seminars for practitioners at Halogen on the topic of SA theory. The seminars focus on the background of SA theory and on how it can be applied to everyday practice. Seminar participants include practitioners who work with safety-critical systems and also other commercial products and services.

This topic presents two main areas of interest. First, how does SA theory influence design practitioners in everyday practice? Second, if design practitioners have a dual mindset that incorporates SA theory and designerly ways, how does this impact the design process and outcome? I would assume that this topic also opens up several other research possibilities, including, for example, method development, instrumental judgement, and designerly ways of knowing.

7.5 Closing remarks

Over the three years of this study, I have regularly reflected on what it means for me as a novice researcher to study design practice. My journey started with design practice and ventured into PhD studies, where I was introduced to research. From there, I transitioned back to practice, but now as a researcher. As I am completing the journey as a PhD fellow and returning to practice, I have started to reflect a bit differently on the gap between practice and research. Central to this new reflection is the question: Do we need to close the gap?

This has led me to a preliminary assumption that – no – this is a gap that can instead be utilised. By this I mean that research and practice are different by default, and they serve different purposes in the design community. Instead of closing the gap, we could deliberately push the boundaries of research by allowing space for non-traditional methods and knowledge claims in practice. As reflected in the sub title of the thesis, I would argue that further exploration of this space should be guided by pragmatism. As Dalsgaard (2014) states, practice takes precedence over doctrines. With this mantra, I hope that researchers and practitioners may obtain relevant knowledge that is applicable to real-world constraints.

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PART 2