Etienne Gernez

HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN SHIP DESIGN

Current ship design processes suffer from two problems. First, the experiences of crew that operate ships are not included in the design process. Second, the collaboration between the different participating designers is not facilitated in the process. As a consequence, the frameworks for understanding the separate parts of ship design can be hard to share across disciplinary gaps. This is especially important between the technical expertise of the ship designers and the operational experience of the end-users.

Human-centred design methods can help addressing these two problems. In particular, ethnography-based methods such as field study observation and analysis can inform the design of ships from the perspective of how ship crew operate them, and how the ship designers design them. Through an experimental introduction of such methods in actual ship design cases, I reframe ship design as a human-centred, collaborative, field-driven process that facilitates the interactions of the different participants to the design process, from the ship designers to the ship end-users.

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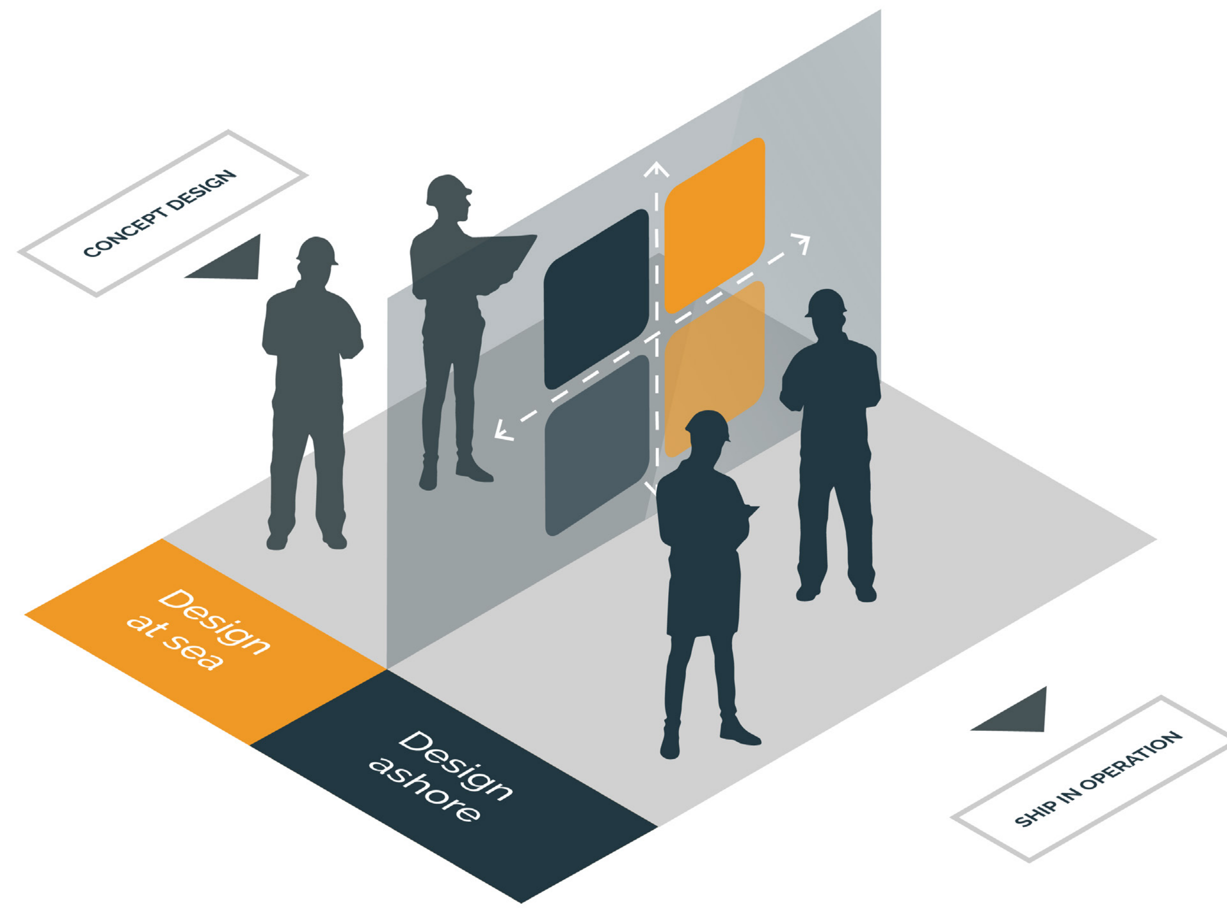

Etienne Gernez

HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN SHIP DESIGN

Implementing field studies for the design of ships in operation

AHO Arkitektur- og designhøgskolen i Oslo
The Oslo School of Architecture and Design

PhD thesis

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ABSTRACT

Current ship design processes have two main problems. First, the experiences of crew who operate ships are not included in the design process. This poses a problem because it limits the ability of ship designers to design ships and ship systems that can be safely and efficiently operated by the ship crew. This is important because design failures can lead to major accidents and inefficient operations. Second, collaboration between the different designers who participate in the process is not facilitated. This is a problem because it limits the ability of the participants to work across their respective disciplines. This is especially important in a complex and multidisciplinary process such as ship design.

Human-centred design methods can help address these two problems. Coming from the traditions of human factors and ergonomics, industrial, and interaction design, these methods deal with the participation and collaboration of all users of a design process. In particular, ethnography-based methods such as field study observation and analysis can inform the design of ships from the perspective of how ship crew operate them. Such a human-centred perspective contrasts with the technology-centred perspective that dominates the maritime industry. The objective of this research is to introduce human-centred methods that are collaborative and field-driven, to be used by industrial and interaction designers, maritime engineers, and human factors and ergonomics experts in ship design processes.

To integrate these methods, I work with the experimental introduction of human-centred methods in actual cases of ship design processes. I analyse the results in terms of what design activities were performed in the cases, and how they contributed to the ship design processes. To structure the analysis, I study the design activities that designers engage with during the design process. This experimental introduction of human-centred, collaborative, field-driven design methods in ship design processes results in the proposition of a design process that combines the human- and technology-centred perspectives and can be used for the design of ships and ship systems.

In addition, I propose a framework that guides the collaboration of maritime engineers, human factors and ergonomics experts, and industrial and interaction designers. These different types of designers have different design goals, specialisation and skills. Specifically, they have a different command and understanding of human-centred design methods. The proposed framework helps connecting different ways to work with human-centred design. It also helps connecting them with technology-centred design activities and data.

When experiencing and designing from the perspective of ship crew, ship designers can improve their ability to design ships and ship systems that are safe and efficient to operate. Further, the introduction of a human-centred perspective on ship operations gives ship designers the opportunity to focus on their own

experience during the design process and improve how they collaborate with each other. As a result, the proposed process and framework have the potential to improve both the design process and its outcome.

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1 INTRODUCTION

Human error is the main source of maritime accidents (Chauvin, Lardjane, Morel, Clostermann, & Langard, 2013; Hetherington, Flin, & Mearns, 2006; Rothblum, 2000). A significant number of these accidents are caused by inadequate designs (Grech, Horberry, & Koester, 2008). These accidents have major consequences in terms of injuries or loss of life, damaged or lost property, and harm to the environment.

To address this issue, there is a need to understand how ship design processes lead to designs that are challenging or inappropriate to use by their human operators. When considering a ship that does not yet exist, how can we integrate its operation into its design process? How much of the work and tasks performed by the ship crew are studied and analysed by ship designers?

Ship designers address this problem from the other end. "[E]nsuring the ship is user-friendly starts with the overall concept produced by the naval architect, but is executed over time by many dispersed members of the design team." (Andrews, 2015, p. 19). If the naval architect does not include operational considerations in the initial concept, the finished product may not include any operational consideration at all. Each participant in the design process shares the responsibility for including operational considerations in their own part of the design work.

What might be their motivation to do so? "Traditionally, when designing a ship, the driving issues are seen to be powering, stability and seakeeping. . . . The hull form then constrains the layout, such that issues related to crewing, ship operations and personnel evolutions can only be investigated within the overall design boundaries." (Andrews & Casarosa, 2005, para. 3). This means that for the naval architect, as well as for the rest of the design team, the way the ship crew will use the ship is of secondary importance.

If the ship design team is not doing it, who might then include operational considerations in the ship design process? Human factors and ergonomics (HF & E) practitioners combine their expertise in psychology, engineering, physiology and biomechanics to design systems that take into account the capabilities and limitations of humans (Grech, Horberry, & Smith, 2002). Andrews (2018a) has argued that ship designers do not need to be HF & E experts, yet they should be able to collaborate with them in the design process. However, some HF & E practitioners have stated that contributing to a ship design process is not straightforward: "Challenges include communication with project owners and the rest of the design team and making them aware of the importance of Human Factors" (Lützhöft, 2015, p. 21).

A preliminary conclusion is that current ship design processes do not place operational issues at the forefront of the design process and that it is challenging for specialists in such issues to contribute their expertise to the design process. This is a problem acknowledged by the maritime industry (Jorgensen, 2018) and it is specific to the design tradition of this industry. In other industries with different traditions of design and engineering, such as industrial and interaction design (Dreyfuss, 2003; Norman, 2013), human-computer interaction (Bødker, 2006), or engineering design (Bucciarelli, 1984), there is an early focus on the end-users of the designed object, how they will use the object and in what context (Kujala, 2003). This is the principle of usability, as defined by the ISO 9241-210 international standard (ISO, 2010). In addition, such design traditions recognise the social dimension of design processes (Bucciarelli, 1984, p. 187):

> "The task of design is . . . as much a matter of getting different people to share a common perspective, to agree on the most significant issues, and to shape consensus on what must be done next, as it is a matter of concept formation, evaluation of alternatives, costing and sizing".

I refer to "human-centred design" (HCD) as a design perspective that emphasises the study of users and their usages of the designed object in a multidisciplinary and collaborative manner (Giacomin, 2014). In this study, I investigate the introduction of HCD design methods into ship design processes. I adopt a practice-based research approach in which I analyse three design cases where I have used HCD methods in collaborative design processes with industrial partners from the maritime industry.

1.1 HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN SHIP DESIGN

A field study is a design method for collecting data about users, their context and their activities (Nova, Lécho Hirt, Kilchör, & Fasel, 2015). It enables designers to interact with end-users in their working and living environments. The data collected during this interaction might be relevant to several participants in the design process, or to several steps of the design process (Blomberg, Burrell, & Guest, 2009). Field studies are recommended when it is difficult for a user to describe his or her work (for example, in an interview) or when the environment in which the object is going to be used has a significant effect on the usability of the designed object (Maguire, 2001). Ships are one example of such a context. As David J. Andrews commented after a conference presentation I gave in 2018, "All naval architects should [and] can only understand mariners' culture if they go to sea" (Gernez, 2018 unpublished material). It is not only a matter of culture understanding – the experience of being at sea has the potential to influence the designer's decisions by adjusting his or her design judgement to an enriched repertoire of situations (Lurås & Nordby, 2015).

The decision to include field studies as a design activity in the design process, however, is not straightforward (Kujala, Kauppinen, Nakari, & Rekola, 2003). Field studies are expensive to carry out because they require travel and time in the field.

They produce a vast amount of data and there is no guarantee that what the designer will be able to observe in the field is what he or she was originally interested in. Even if the data collected in the field is relevant to the design problem at hand, the designer still needs to translate the captured insights into usable design data for him or herself, and most likely for a larger team (Diggins & Tolmie, 2003).

As such, field studies used in ship design processes are one example of a HCD method that helps capture and analyse data about the operation of the ship (Figure 1). Because only a fraction of the ship design team will have the opportunity to go into the field, and because the rest of the team is handling different parts of the ship design process, the use of field studies necessitates a strategy for facilitating the handover and the multidisciplinary analysis of field insights. In other words, ship designers that decide to include a field study in the design process will have to deal with a human-centred and collaborative design process. The object of my study is to define such a human-centred, collaborative, field-driven ship design process and to describe how to go about it.

My study is directed towards naval architects and maritime engineers as well as industrial designers, interaction designers and HF & E practitioners. Its message for the first group is that there is a need to implement human-centred, collaborative, field-driven design methods in ship design processes. For industrial and interaction designers, this study describes how to use familiar methods in a specific context that they might not yet be familiar with: designing for the maritime industry. For HF & E practitioners, it offers a framework to facilitate their contribution to ship design.

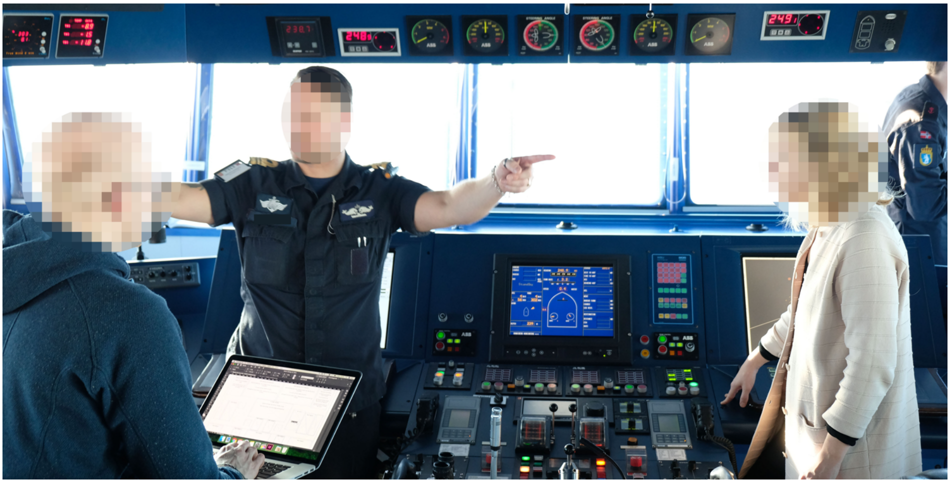

Figure 1: Two designers working with an informant during a field study on a ship bridge, with permission from SEDNA project, the Oslo School of Architecture and Design (AHO, 2019).

To avoid confusion between designers with a maritime engineering background and those with a background in industrial and interaction design or in HF & E, I refer individually to each group, i.e. “maritime engineers”, “industrial or interaction designers” and “HF & E practitioners”. When I include all three groups together, I refer to them as “designers” or “ship designers”. I use a broad definition of “ships” to include other similar objects, such as submarines, offshore platforms and any kind of large floating object.

1.2 RESEARCH AIMS AND QUESTIONS

Based on my work I argue that in order to produce more adequate designs, current ship design processes face three types of problems or research gaps:

1. Participation gap: the lack of end-user involvement in the ship design process
2. Collaboration gap: the lack of facilitation of human-to-human collaboration among the participants in the design process
3. Connection gap: the challenge in connecting the experiences of ship end-users with the needs of the design process

To address these three gaps, my research aims to:

- introduce human-centred, collaborative, field-driven design methods,
- that can be used by industrial and interaction designers, maritime engineers and HF & E experts; and
- to carry out ship design processes centred on the experience of ship end-users in operating the ship.

In light of these aims, my research is organised around the following questions:

1. How are users and user data integrated in current ship design processes?
2. What benefits might occur when implementing human-centred, collaborative and field-driven methods in ship design processes?
3. How might we model human-centred, collaborative and field-driven ship design processes?
4. How might we better connect the operational experience of the ship crew with the design work of the ship design team?

To address these questions, I used a case-based research approach, which is built upon a cognitive view of design, described in the next section.

1.3 DESIGNING AS CONSTRUCTION OF ARTEFACT REPRESENTATIONS

In her observation of how designers, architects and engineers work, Visser proposed that designing is the activity of constructing representations of artefacts (Visser, 2006a, 2006b, 2009). Goldschmidt explains that this activity takes place throughout the design process until the designer arrives at "a satisfying representation of the designed entity" (Goldschmidt, 2004, p. 203). Visser and Goldschmidt use a cognitive view of design that focuses on what designers are doing, their design activities and their representations of the design process and of design artefacts. I use design activities and representations of design artefacts as units of analysis to describe current ship design processes. The cognitive view of design helps me study how human-centred, collaborative, field-driven design methods are used by industrial and interaction designers and to derive how they might be combined with current ship design activities.

I also use this type of cognitive analysis to break down ship operations into work tasks performed by the ship crew when they are operating the ship. This analysis is a common practice in HF & E research (e.g Hutchins, 1995; Stanton et al., 2013). HF & E often include the analysis of other types of tasks, including social tasks (Lützhöft, 2004), organisational, commercial and others (Vicente & Rasmussen, 1992). In human-computer interaction (HCI) and disciplines such as computer supported collaborative work (CSCW) and workplace studies, the lens of analysis is balanced between social and technical aspects (Luff, Hindmarsh, & Heath, 2000). To limit the scope of this study I focus on the work tasks performed by the ship crew and refer to these tasks as "operation activities"; performing some of these activities might require the ship crew to engage in social interactions. In the same way, I focus on the work tasks performed by designers and refer to them as "design activities".

The use of the same unit of analysis to describe the work of the ship crew and ship designers creates a form of continuity in the model of ship design that I am proposing. For example, one fundamental design activity in this model is the capture of end-users′ experiences. One type of input to this design activity is the observation of the ship crew engaged in operation activities. One type of output from this activity is a design requirement for a ship system that end-users are interacting with during operational activities.

I applied this approach to carry out my research in the conditions described in the next section.

1.4 CONDITIONS OF THE STUDY

Before this PhD study, I was an employee at DNVGL, an advisory and regulatory company that approves ship designs and provides consultancy services for the design and operation of ships. This job gave me access to collaborate with engineers and ship owners who worked with projects dealing with ship design and ship operation. This work experience and knowledge of the maritime domain has been important in my research.

The research presented in this thesis took place at the ONSITE research project where I worked with three design cases in collaboration with three industrial partners. ONSITE gave me access to ships for context and to ship crew as informants, enabling me to experimentally introduce methods of observation, analysis and co-design in collaborative, HCD processes.

In the first design case, I conducted a field study onboard a platform supply vessel to study how to improve the experience of working in engine rooms (Figure 2). I conducted the study alone during five days onboard the ship in the North Sea in December 2016. Through documenting users' workplace experiences, this case informed questions about how to connect field studies with ship design (Gernez, Nordby, Seim, Brett, & Hauge, 2018).

The second field study took place in February 2017 on a roll-on/roll-off ship while it was berthed at a harbour in Norway. I conducted the study with my PhD supervisor, who has experience with field-driven design in the maritime domain. This field study focused on the work of ship surveyors, who inspect a whole ship in one day (Figure 3). During this short time, the surveyors inspect several ship locations together with the ship crew to assess the condition of the ship systems and evaluate the crew's work practices. Thus, the surveyors' work is based on field observation and analysis. The design brief for this case was how to support the surveyors' work. This case informed questions about how to organise and handle data produced in a field study.

Figure 2: ONSITE Case #1: following a mechanic changing an oil filter in the engine room.

Figure 3: ONSITE Case #2: following a ship surveyor during a ship inspection.

The third field study focused on mapping a large fishing ship's trawling and fish processing operations (Figure 4). I conducted the study in September 2017 with three maritime engineers working on the design of a new type of fishing vessel. This case informed questions about connecting field studies with ship design and how to involve maritime engineers with no experience in HCD methods in a field-driven design process.

Figure 4: ONSITE Case #3: mapping the operations in a fishing vessel.

In addition to these three design cases based on three field studies, I took part to two field studies on passenger vessels while leading a field study course for two years at the Oslo School of Architecture and Design (AHO). My role during these studies was to assist the course students who were performing the field study.

Working with the field study course contributed to building a comprehensible model of field-driven design in the maritime industry.

1.5 PUBLICATIONS

My research is the sum and result of four publications. I also build upon six other publications not included in this thesis.

1.5.1 Publication 1: Human-centred, collaborative, field-driven design – a case study

We describe a case where HCD methods were experimentally introduced into a ship design process (Gernez et al., 2018). We observed that a field study combined with workshops can address some participatory and multidisciplinary needs of ship design as well as producing innovative concepts. We also observed that this process motivated the design participants to shift the focus of their design activities to the end-users' experiences.

1.5.2 Publication 2: Connecting ship operations and ship architecture to ship design processes

I make the case that current ship design processes focus on the ship as a technological object rather than on its use by ship crew. I make the distinction between a technology- and a human-centred perspective for ship design. I propose a framework designed to connect these two perspectives, their associated design methods and data (Gernez, 2019). The connection takes place through the use of field studies, workshops and prototyping activities. These activities also connect two fundamental dimensions in the design process: the "as-is" dimension of what is known and exists already and the "preferred" dimension of what could be, should be or ought to be.

1.5.3 Publication 3: Implementing field research in ship design

We describe in detail a generic design process that integrates human-centred methods in ship design processes (Gernez & Nordby, in press-b). For each step of the process, we present what tasks need to be carried out, what data is generated and how the data is used in the next step.

1.5.4 Publication 4: A 10-day course to plan and execute field studies for maritime design processes

In the last publication, we describe a course introducing this type of design process to students familiar with HCD methods (Gernez & Nordby, in press-a). The course is based on participation in a field study and its subsequent analysis. The students are asked to reflect upon their experience while taking the course. The challenges they describe are analysed to evaluate how the course´s learning objectives were addressed.

1.5.5 Publications not included

The work presented in the four publications included in this study builds upon three other publications. The first one presented an early vision of how a human-centred perspective could be introduced into technology-centred ship design processes (Gernez, Nordby, & Sevaldson, 2014). This publication proposed a human-centred mapping technique that I have used in the design cases at ONSITE and in Section 5.1.1 of this study. In the second publication we proposed to apply human-centred knowledge sharing principles in order to facilitate collaborative projects in the maritime industry (Gernez & Nordby, 2015). This publication was a first exploration of the theme of collaboration through the lens of knowledge sharing in organisations, which I did not pursue further in this study. In the third publication we presented a case conducted with two industrial and interaction design students on the use of virtual and augmented realities for the preliminary design of workplaces on ships (Nordby, Børresen, & Gernez, 2016). This publication helped me become familiar with how interaction designers work.

In addition, through the ONSITE project, I have contributed to the development of software supporting field studies. To that end I have contributed to the description of the information and data contained in reports from field studies (Nordby, Schaathun, Gernez, & Lurås, in press) and to the analysis of the challenges of building a knowledge management system based on data collected in field studies (Schaathun, Tran, Tollefsen, & Gernez, 2017). Another publication (in progress) looks at the design of digital tools to support the field study process (Schaathun, Nordby, Saad, & Gernez, unpublished manuscript). These three publications deal with field studies from a computer science perspective, so I have not included them in this study in order to focus on the design process and design methods aspects of my research instead.

1.6 CONTRIBUTIONS

The first contribution of this study is to reframe ship design processes using a human-centred perspective. The resulting process contrasts with current ship design processes in its ability to (1) include ship end-users' experiences and (2) to facilitate the collaboration of design participants such as ship end-users (as informants in the design process), ship designers and sub-contractors for the ship designer. This contribution addresses the "Participation" and "Collaboration" gaps introduced in Section 1.2.

The inclusion of end-users and the facilitation of human-to-human collaboration relies on the use of field studies as a central design activity in the ship design process. My second contribution is a framework in which field studies are combined with other design activities that stem from current practices in maritime engineering, HF & E and industrial and interaction design. This combination of design activities connects the operational perspective of the ship crew with the design work of the ship design team. The third contribution of this study is an analysis of how such a connection takes place, which addresses the “Connection” gap.

1.7 STRUCTURE OF THE THESIS

Figure 5 (next page) gives an overview of the study. The presentation of my research is organised in four parts:

1. A study of the research context, which presents the status quo and state of the art in the maritime industry along with relevant published literature (Chapter 2 – Context of the study).
2. A description of my design practice and how I used it in my research (Chapter 3 – Research approach).
3. A summary of my research findings and a presentation of the contributions of my research (Chapter 4 – Research findings and Chapter 5 – Contributions).
4. A discussion of the originality, solidity and relevance of the research, followed by a conclusion (Chapter 6 – Quality of the research and Chapter 7 – Conclusion)

The four publications are included after the references (Chapter 8). In the next chapter I present the context of the study in more detail.

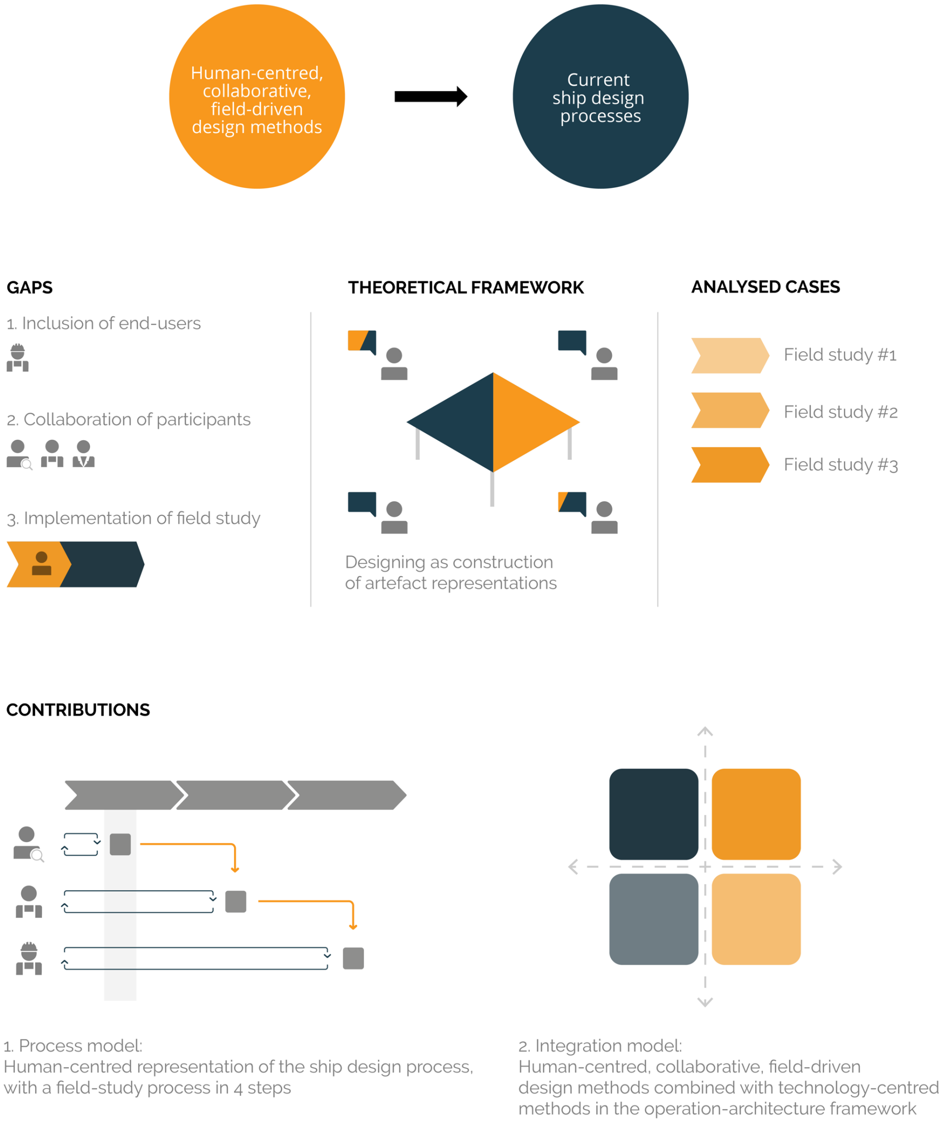

Figure 5: Overview of the study.

2 CONTEXT OF THE STUDY

I review the current practices in ship design, HF & E applied to the maritime industry and the application of design methods originating from the industrial and interaction design traditions in the maritime domain. I also present the theoretical framework that studies how designers engage with design activities. To begin, I give a short presentation of how the context review was carried out.

2.1 CONTEXT REVIEW METHODOLOGY

The context review is based on knowledge gained from my working experience as a maritime engineer and a literature review. In the early stages of my research, I approached the literature review with a broad scope, first to understand the variety of topics involved in ship design and HCD, and then to progressively build relationships between them. The literature review progressed organically (i.e. without a specific system) throughout the different phases of my research. I performed multiple searches with keywords, I screened entire journal collections and I examined the entire output of key researchers. Figure 6 shows a view of this work process in a picture of my office wall dating from February 2018. As my research progressed, I worked with additional researchers, themes and publications, and built new relationships between them.

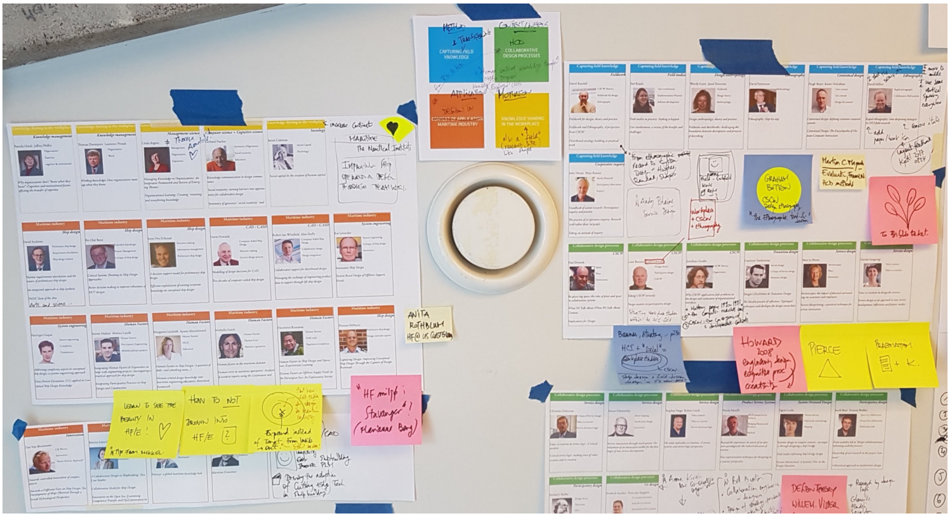

Figure 6: Photo of my office wall (February 2018): context review work process.

The literature review was based primarily on the source material presented in Table 1 and Table 2, which is organised by journals, conferences, keywords and researchers.

Table 1 *Primary source material for the ship design context study*

Journals	Transactions of the Royal Institution of Naval Architects
	International Journal of Maritime Engineering
	Computer-Aided Design
	Journal of Ship Production and Design
Conferences	International Marine Design Conference (IMDC)
	International Conference on Marine Design (arranged by the Royal Institution of Naval Architects)
	International Conference on Computer and IT Applications in the Maritime Industries (COMPIT)
	International Conference on Human Factors in the Design and Operation of Ships (arranged by the Royal Institution of Naval Architects)
Keywords	ship design, collaboration, human-centred design, participation, field study

Table 2 *Primary source material for the HCD context study*

Journals	Human-Computer Interaction
	Interacting with Computers
	Design Studies
	CoDesign
	Journal of Applied Ergonomics
Conferences	Computer Supported Collaborative Work (arranged by the Association for Computing Machinery)
	Special Interest Group on Computer-Human Interaction´s Conference on Human Factors in Computing Systems
	Conference on Designing Interactive Systems
	Participatory Innovation Conference
	Service Design and Service Innovation Conference
Keywords	human-centred design, CSCW, codesign, collaboration, participation, field study

As shown in Table 1, I focused on ship design research originating from the maritime engineering research tradition. In addition, I searched for cases of HCD and HF & E research that took place in the maritime domain in the source material described in

Table 2.

2.2 SHIP DESIGN

I present a review of commonly used ship design models in order to elucidate the preliminary observation made in the introduction chapter that ship design processes do not place operational issues at the forefront of the process. A more refined observation is that most ship design models are centred on the ship as a technological object, and consequently do not consider the operation of the ship by its crew as part of the design process. I present how such design models are built and offer counter examples. The selection of models included is based upon the state-of-the-art reports on ship design in recent volumes of the IMDC proceedings (Andrews, Duchateau, et al., 2012; Andrews & Erikstad, 2015; Andrews, Papanikolaou, Erichsen, & Vasudevan, 2009).

2.2.1 Technology-centred ship design processes

Ships are large and complex objects made with numerous components. Morais, Waldie and Larkins made the following comparison of cars, planes and ships: cars have an average of 5,000 parts, planes 100,000, and complex ships can have more than one million (Morais, Waldie, & Larkins, 2011). A number of ship design processes reflect this technological complexity by adopting a technology-centred perspective.

The ship design spiral model was proposed in 1959 by Evans (1959) and has remained one of the most utilized. The model is built upon the calculations required to work out the fundamental features expected in a ship: a specific cargo capacity, a certain amount of floatability and stability, and the ability to move through water at a specific speed using a certain amount of power. The model is linear and sequential: each type of calculation is performed one after the other, and the procedure is repeated until a balance is obtained between the different requirements (Figure 7). The model has been criticised for locking ship designers into a type of design solution early on in the process and preventing them from coming up with innovative design proposals (Andrews, Percival, & Pawling, 2012; Levander, 2003; Wijnolst, 1995). More recent versions of the model are based on performing the different calculations, not sequentially, but in a concurrent manner, using multi-objective optimisation techniques (Papanikolaou, 2010).

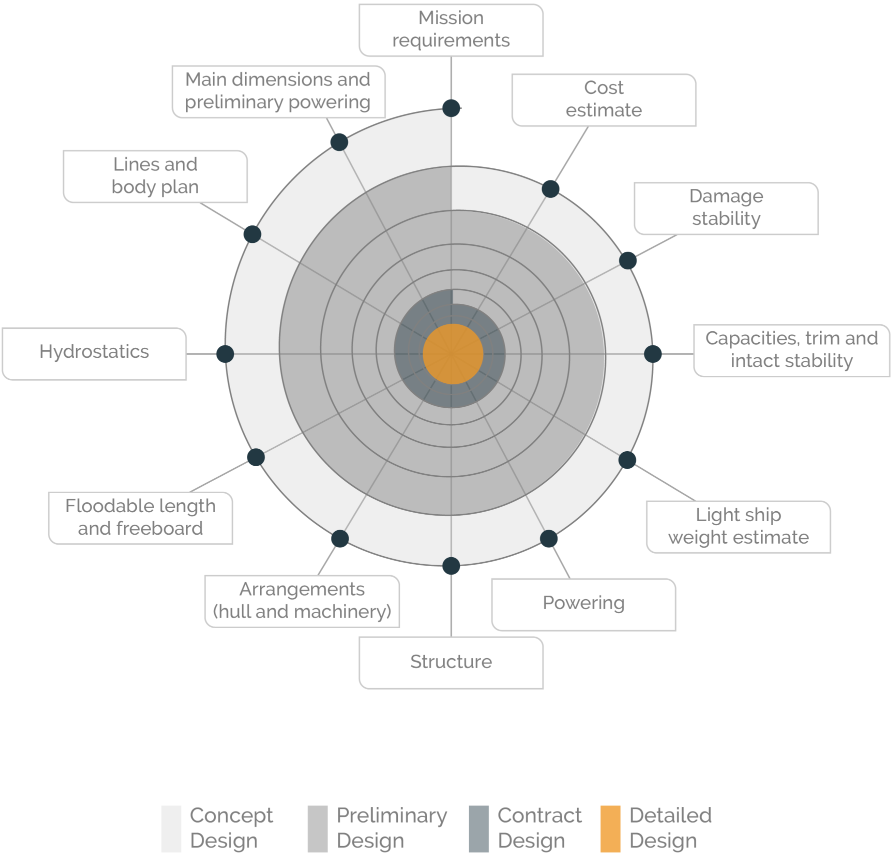

Figure 7: Model of Evans´s ship design spiral model, updated by Papanikolaou; reproduced from Papanikolaou (2010).

Professor David J. Andrews is one of the most published and cited researchers in ship design. Andrews´s approach to ship design starts with what he refers to as the "requirements elucidation", which is also a term used in software engineering and other engineering disciplines (Andrews, 2003b, 2011). It consists of working out what the customer wants with respect to what the naval architect can deliver. One could argue that this is a human-centred approach; however, as I will explain in Section 2.4.1, facilitating a dialogue with the customer requires the use of specific design methods and a specific context of inquiry, which Andrews does not elaborate upon. Andrews´s focus on customer requirements is actually an isolated example. Ulstein and Brett (2012) reviewed 29 different ship design models and found that more than half of the reviewed processes do not start by capturing the needs of the customer (i.e. the future owner of the ship).

Andrews worked specifically with the preliminary phases of ship design and focused on what he termed the “ship synthesis”, or the process by which “ship designs are created ab initio” (Andrews, 1985, p. 73). Andrews refers to the “architectural and engineering synthesis” (Andrews, 1985, p. 76), which consists of “a geometric realisation of the ship” in which its various parts and compartments are located with respect to each other, as seen for example in a general arrangement drawing (Figure 8). As such, Andrews makes the distinction between the “ship architecture”, which refers to the built parts of the ship (with their allocated location and function) and the “ship design”, or the process leading to the development of the ship architecture. I adopt the same naming convention in this thesis and follow this distinction between ship design (the design process) and ship architecture (the designed artefact). Furthermore, I refer to the “ship operation” as the use of the ship by its human operators, either an actual use, or a possible future use.

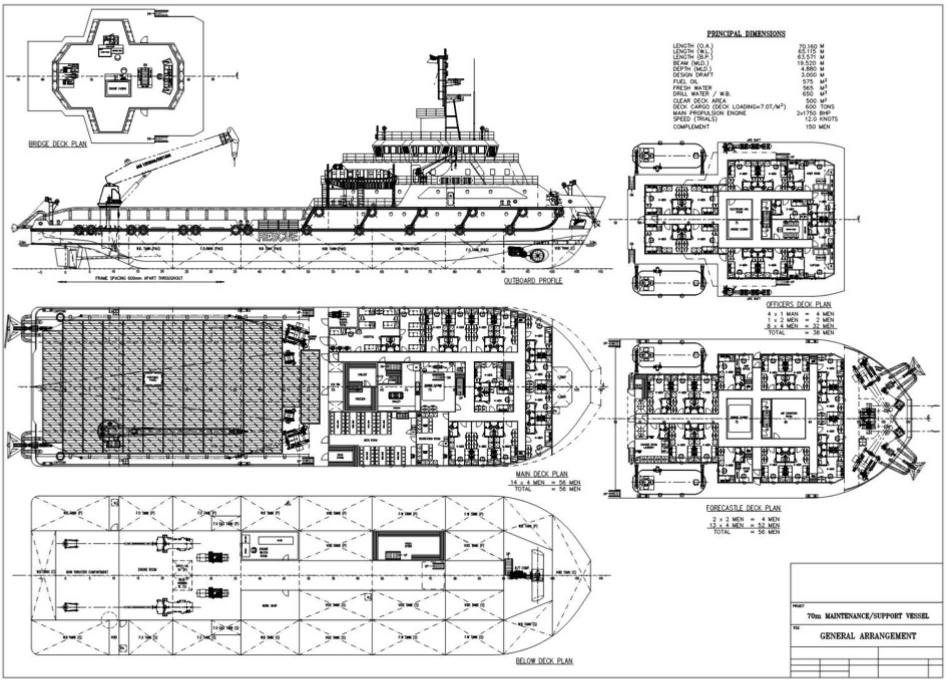

Figure 8: A general arrangement drawing, retrieved online (Vimatec, 2018).

Nowacki has been one of the main contributors to the development of computer-aided ship design (CASD) since the 1960s (Nowacki, 2010). He proposed the generic model reproduced in Figure 9 (Nowacki, 2009). The model is based on the creation of a formal problem with a set of design variables whose values are found through an iterative exploration of possible solutions that are developed under various scenarios. This is a pure problem-solving model in which the composition of the problem and solution spaces are constrained by the way the designer decides to formalise the problem. With the increase of computing power and the capability to collect and work with a greater amount of data, some authors refer to "data-driven ship design" (H. Gaspar, 2018). In this type of formalisation, "data" refers to quantitative data describing the state of a ship property variable, rather than qualitative data describing the experience of the end-user of the ship.

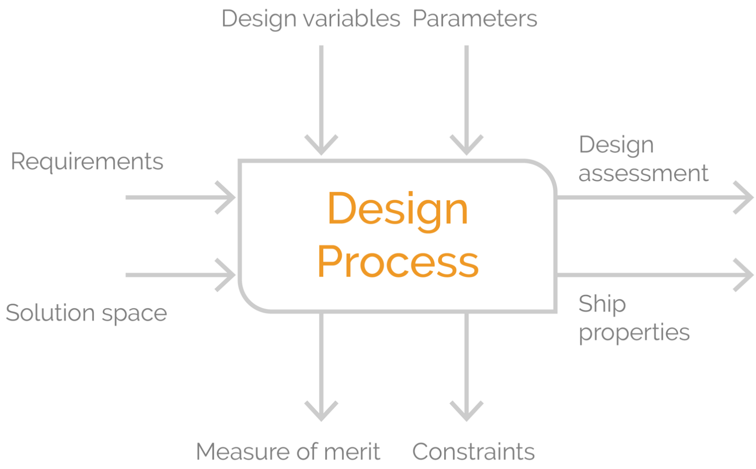

Figure 9: Generic ship design process model, reproduced from Nowacki (2009).

The formalisation approach introduced by Nowacki follows the development of optimisation approaches where CASD tools are used to define different requirements, constraints and parameters, for which optimal solutions can be found in concurrent processes (e.g Mistree, Smith, Bras, Allen, & Muster, 1990; Whitfield, Duffy, Gatchell, Marzi, & Wang, 2012). Reflecting on their experience with such tools, Ulstein and Brett observed that "the complexity and lack of human capacity and capability to handle all the variables and their influences within a meaningful context for everyday decision-making is perhaps not as could be hoped for" (Ulstein & Brett, 2012, p. 373). Andrews recommended that such tools should include new developments "that both foster insight and creativity, rather than just provide faster and more detailed numeric analysis" (Andrews, 2013, p. 45).

Systems engineering is based on a decomposition of a system into sub-systems, for which requirements and solutions are produced, before being reassembled into a coherent whole. In the 2009 IMDC State of the Art Report on Design Methodology, Andrews et al. (2009) observed that systems engineering is being adopted by a growing number of ship designers. They noted some similarities between the systems engineering approach and Andrews´ model of ship synthesis, but critiqued systems engineering for not supporting the creative process as well as ship design synthesis (Andrews et al., 2009). However, they acknowledged that systems engineering approaches are convenient for the project management aspects of ship design.

Design for X is a framework based on the systems engineering approach combined with CASD optimisation techniques. The "X" represents different objectives for which the process can be set-up to optimise. In the second part of the IMDC 2009 State of the Art Report on Design Methodology, Papanikolaou et al. presented techniques to optimise the design for "safety" (Papanikolaou et al., 2009, p. 582), "efficiency of performance" (Papanikolaou et al., 2009, p. 593), "arctic operations" (Papanikolaou et al., 2009, p. 604) and "production/productability (sic)" (Papanikolaou et al., 2009, p. 612). This approach illustrates the variety of interconnected problems a naval architect needs to confront at the same time. Papanikolaou et al. remarked that it is up to the naval architect to decide what problem to prioritise and how to balance it with other aspects of ship design (Papanikolaou et al., 2009).

As presented in Publication 2 (Gernez, 2019) and in Section 4.2, I searched the 27 models of ship design presented in the 2009 IMDC State of the Art Report on Design Methodology (Andrews et al., 2009) for references to ship operation. I found that fewer than half of the published models explicitly referred to the operation of ships. Together with the examples of models presented above, this shows that ship design processes are predominantly technology-centred. This focus is important because it limits their ability to address the use of the ship by the crew, thereby creating conditions for designing ships that have suboptimal or even inadequate solutions. There are, however, exceptions, which are presented in the next section.

2.2.2 Human-centred perspectives in ship design research

For the first time since the its inception in the 1980´s, the 2018 edition of IMDC featured an agenda item related to HCD and included design practices from industrial design. The call for participation to the conference contained the following topic: "the challenges in merging ship design and marine applications of experience-based industrial design" (IMDC Committee, 2018). Out of a hundred papers presented at the conference, three papers addressed this topic. The first paper dealt with integrating elements of local culture in the design of traditional fishing boats in Indonesia (Birmingham & Wibawa, 2018). The second paper presented findings from the observation of passenger vessels and their safety measures (Ahola, Murto, & Mallam, 2018). The third paper was the case of human-centred, collaborative, field-driven design included as Publication 1 in this thesis (Gernez et al., 2018).

Ship design management models introduce the distinction between the process of designing a ship and the process of managing the ship design process. Kuo (2003) emphasised that ship design is about decision-making, but did not introduce tools either to analyse or facilitate the decision-making process. Ulstein and Brett argued for the need of management techniques to deal with the multidisciplinary and complexity aspects of ship design: "Next generation ship design models and approaches should . . . include also the necessary management tools, social science and support mechanisms to handle the extended system-based [sic] ship design process" (Ulstein & Brett, 2012, p. 373).

Van Bruinessen (2016) interviewed designers and observed their work throughout several ship design projects. He analysed these observations in terms of the evolution of the architecture of the designed ship, not in terms of the interactions among the designers. In another publication, Van Bruinessen, Hopman and Smulders acknowledged that human-centred research methods would be required to study this latter aspect and that herein lies a central research challenge: "further research is required, but exploring this social dimension is complex: it requires research skills related to the social sciences, but sufficient knowledge is required to understand the subject matter." (Van Bruinessen, Hopman, & Smulders, 2015, p. 514). The alternative that I propose in this study is to focus on the tasks carried out by designers in order to find out how they might combine their design perspectives during the design process.

Andrews et al. and Casarosa worked on integrating a simulation of the ship crew's movements during the preliminary phase of ship design (Andrews et al., 2008; Casarosa, 2011). They did not perform interviews with the ship crew to evaluate the simulations and their approach. DeNucci worked on a procedure to capture the "design rationale" in the early phases of a ship design process by developing a software that would keep track of the discussions of ship owners and maritime engineers and how these discussions were formalized into design requirements (DeNucci, 2012). De Nucci focused on the development of the software architecture, but not on its use in a design process.

In Portugal, Gaspar and colleagues from the Centre for Marine Technology and Ocean Engineering worked on the layout of a mooring deck and the design of a winch control station (J. Gaspar et al., 2016). They followed a design process based on two standards: the ASTM Standard Practice for Human Engineering Design for Marine Systems, Equipment and Facilities (ASTM International, 2013) and the Guidance Notes on the Application of Ergonomics to Marine Systems (American Bureau of Shipping, 2014). This is the only example I came across of a design case that used a HCD process published in maritime engineering research. In Sections 2.3 and 2.4, I present additional cases published in the HF & E and industrial and interaction design domains, respectively.

Finally, there is the case of passenger ships and cruise ships. The users of such ships are both the ship crew and the passengers, and a significant part of their operation is a matter of hospitality management (Gibson & Parkman, 2019). As such, the design process is closely related to the design of experiences, for instance the passenger experience (Ahola & Mugge, 2017; Johansson & Naslund, 2009). The two field studies that took place on passenger vessels in ONSITE were carried out by the design students taking the field study course, I was only mentoring the students and did not take part to design activities. Because of the nature of the rest of the design cases I worked with for the ONSITE project, I did not explore in further detail the question of combining ship design with the design of passenger experiences.

2.2.3 Summary

Ship design processes are dominantly technology-centred. They focus on the ship and its systems as a technological object. As Andrews has done, I refer to the term "ship architecture" in order to describe this part of the scope of the ship design process. The other part of the scope of ship design, which focuses on the operational tasks carried out by the ship crew when using the ship, is not included in current ship design processes. As a consequence, there is a lack of inclusion of end-users, their operational experiences and the design methods that could address this issue. Another consequence is a lack of focus and methods to facilitate collaboration among the design participants, including ship end-users as informants in the design process, ship designers and sub-contractors working with the ship designer and the customer of the ship designer. As Ulstein and Brett put it, "existing and more traditional ship design approaches are particularly weak when it comes to handling and cater to a multi-dimensional and multi-disciplinary complex ship design approach." (Ulstein & Brett, 2012, p. 373).

Going beyond the perspective of the design process, there is also a gap in terms of competence. Andrews argued that the naval architect, as the lead designer of a ship, does not need to become an expert in all disciplines involved in ship design, but should, however, be able to understand the terminology, methods and tools used in a number of these disciplines (Andrews, 2018a, 2018b). This view requires that the naval architect is also trained to collaborate with other specialists, although Andrews did not discuss it.

HF & E is a discipline with the appropriate methods and competence to deal with the observations of ship end-users, the analysis of their work tasks and their experienced challenges. I describe in the next section how HF & E is applied to design processes in the maritime domain.

2.3 HF & E IN THE MARITIME INDUSTRY

HF & E were only recently applied to the maritime context, with an initial conference dating back to 1979 (Anderson, Istance, & Spencer, 1979). As seen in Chapter 1, it is challenging for HF & E practitioners to collaborate within ship design processes. It is a domain that is still separated from the ship design literature produced in maritime engineering circles such as the IMDC conferences. In the 27 models of ship design presented in the 2009 IMDC State of the Art Report on Design Methodology (Andrews et al., 2009), I found only one reference to "Human Factors" as an example of a management tool, under the category of "project management issues", in a model presented by Andrews (1998, fig. 8 p.209).

Such disconnection between ship design and HF & E is an important problem because it reduces the ability of maritime engineers to use the competence and perspectives of HF & E experts when analysing user experience and the context of use. Conversely, as presented in Section 2.2.3, ship designers do not consider HF & E as part of the necessary set of competences to acquire. Rather, ship designers are expected to be able to work with HF & E specialists. Petersen (2012) used auto-ethnography to study how usability is practiced by maritime engineers. He concluded that there was a need to educate maritime engineers about what usability consisted of, how to practice it and what it would enable them to achieve. Additional publications (Petersen, Nyce, & Lützhöft, 2011; Vries, Hogström, Costa, & Mallam, 2017) show the gap between the types of knowledge with which maritime engineers work and those recommended by HF & E practitioners, especially concerning concepts of usability and designing for safety.

At the Australian Maritime College, Abeysiriwardhane used field studies to develop educational programs for final-year naval architecture students (Abeysiriwardhane, 2014, 2017). Students were taken on a short boat trip and then asked to reflect on how the experience might affect their practice. "Champions" of HCD methods led groups of naval architecture students with no previous education in HCD methods and had them perform HCD design activities. Educating a new generation of naval architects and maritime engineers about HF & E issues and methods is one way to progressively add these ideas into the agenda and design considerations of ship design processes. Another way is to facilitate collaboration in ship design processes with the objective to combine methods, expertise and levels of expertise from all the design participants. This is the way I have chosen to follow in this study.

In the next sections I present a few central topics concerning HF & E in the maritime domain and how these publications relate to the questions of human-centredness, the inclusion of end-users and the facilitation of design participants' collaboration.

2.3.1 Organisational and technical challenges

Organisational challenges is a central item in the scope of HF & E (Grech et al., 2008). Although not HF & E specialists, Morais, Waldie and Larkins describe an important specificity of the organisation of ship design processes in which repeatedly there is a monetary incentive to design a solution that has only short-term benefits (Morais et al., 2011). For example, during the preliminary design phase, ship designers need time to work out design decisions that will affect the rest of the design process, but they cannot invoice this work until a contract is signed with the ship owner. In such a situation, a lack of collaboration can have significant consequences because eventually the responsibility of producing a product that is safe and efficient to use ends up being distributed over time and across different companies. The same logic applies in the construction phase when shipbuilders do not get paid until they deliver the ship, incentivising them to work quickly to reduce their own expenses. In both cases, it is then challenging to bring human-centred considerations such as ergonomics into the design process, which might seem to increase the list of requirements to address and further complexify the problem.

2.3.2 Regulatory aspects

Organisational challenges relate to how companies and their employees deal with the professional standards they set for themselves and the regulations they are subjected to, for example through the focus on safety culture (Grech et al., 2008). The International Maritime Organization (IMO) puts a strong emphasis on the work of seafarers: "The safety and security of life at sea, protection of the marine environment and over 90% of the world's trade depends on the professionalism and competence of seafarers." (IMO, 2019). As such the IMO is working with the concept of the "human element", defined as "a complex multi-dimensional issue that affects maritime safety, security and marine environmental protection involving the entire spectrum of human activities performed by ships' crews, shore-based management, regulatory bodies and others." (IMO, 2019). Ship designers are not mentioned explicitly in this definition, but there is a large body of IMO publications in which HF & E principles for ship design are relevant. Lützhöft and Vu list a total of 18 documents, such as assembly resolutions and circulars from the maritime safety committee and the sub-committee on navigation, communications and search and rescue as well as the Safety of Life at Sea (SOLAS) convention (Lützhöft & Vu, 2018).

Mallam and Lundh (2013), as well as Sørensen and her co-authors (2018), studied the IMO regulations for ship engine rooms and ship bridges, respectively. They found evidence that the HF & E principles introduced in the design regulations did not align with the regulations of the operation of these ship parts. In the case of bridge design, the problem lies in the regulation concerning the size of the crew: “The number of staff and their competence may be adequate . . ., but the bridge layout and design may not permit safe resource management” (Sørensen, Lützhöft, & Earthy, 2018, p. 1). In the case of engine room design, compliancy with the design regulation does not guarantee compliancy with the operational regulation, or as Mallam and Lundh summarise, the “work environment design does not support user needs” (Mallam & Lundh, 2013, p. 523).

The regulatory landscape is complex; there are other layers of regulation in the rules and guidelines edited by Classification societies and the requirements enforced by individual ship owners. Looking only at the highest level of international regulation (for instance the IMO), there is evidence of a disconnect between the principles governing ship design and ship operation. Thus, there is a need to connect design activities with the analysis and representation of operational work tasks. Whatever the content of the regulatory documents, designers should be supported in prioritising the aspects of ship operations they deem necessary.

2.3.3 Human error and inadequate designs

Human error is another central concept in HF &E practice. Anita Rothblum defines human error as either an incorrect decision, an improperly performed action or the lack of action or inaction (Rothblum, 2000). There are several factors that can trigger human error, such as organisational factors, the work environment or technology. The more these factors are combined, the more chances for a human operator to commit a human error. As such, Rothblum argues that designers must understand and support the tasks of the operators, and strive to design solutions that can fit into the other design solutions present in a work context (Rothblum, 2000).

One common way to detect human error is with quantitative, statistical analyses performed retrospectively on accident report databases (Grech et al., 2002; Kataria, Praetorius, Schröder-Hinrichs, & Baldauf, 2015; Praetorius et al., 2015). The problem with this type of detection of human error is that it only shows errors that actually took place, though “near misses” are often reported as well. However, situations that are potentially problematic, but that do not trigger an accident or a near accident cannot be uncovered this way. As Lützhöft observed, “when designers do not take their views into account, users do adapt to the workplace when forced to, but adaptations and workarounds are signs that the design should have been better” (Lützhöft, 2015, p. 21). When the crew adapts to inadequate designs, it becomes part of their normal work tasks, which makes it challenging to spot in an interview session taken outside of the work context when the designer does not have the opportunity to observe and experience first-hand the work of the end-user.

A more proactive way to detect situations in which human error might happen is through qualitative analyses such as field studies. Monica Lundh combined field studies with semi-structured interviews to study the working conditions in the engine departments of ships. Together with her co-authors, she found that the design of the engine room directly affects the crew's performance. In addition, the ship crew's adaptation to the working environment increases the risk of exposure to hazardous substances and the possibility of injuries (Lundh, Lützhöft, Rydstedt, & Dahlman, 2011).

Lützhöft framed field studies as "problem-oriented ethnography". As such, field studies are a form of ethnographical study, with a specific scope, that focuses only on a few selected parts of a particular context (Lützhöft, 2004, p. 29). One topic she worked with is the importance of the distinction between "wants" and "needs", and how problem-oriented ethnography can help make this distinction (Lützhöft, 2004). In the example of Andrews´ requirement elucidation (Section 2.2.1), the customer of the naval architect is the ship owner, whose "wants" might be related to technical, organisational and commercial requirements, for example the cargo and power capacity, without necessarily considering the operational "needs" of end-users of the ship, i.e. the ship crew.

Using a method of the "think-aloud" type (Stanton et al., 2013), designers can document how users think when they perform a work task. As such, field observations help not only to study what type of potential human errors might happen, but also why they might happen. Finally, inadequate design and human error are not only linked to safety, but also to energy efficiency as well (Jensen et al., 2018; H. B. Rasmussen, Lützen, & Jensen, 2018). One example of data that requires a field-driven approach is the direct feedback of users during a test of a prototype. For instance, Porathe and Prison worked with the design of a human-map system interaction and the design of map systems for ship bridges, testing prototypes through lab experiments and field studies (Porathe, 2006; Porathe & Prison, 2008).

2.3.4 Design process

In what types of design processes are HF & E methods implemented? I give a few examples below, but this list is not intended to be exhaustive list and does not refer to, for example, risk analysis methods.

HF & E methods in the maritime domain follow a user-centred, usability-focused interpretation of HCD based on the ISO 9241-210 standard (Laffoucriere, 2015). In this standard, usability is defined as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2010, p. 3). The ISO 9241-210 standard gives recommendations for budgeting for human-to-human facilitation activities and for what competences to include in the design team. The standard recommends allocating for specific activities such as collecting user insight and evaluating design solutions together with users. In addition, the standard recommends allocating additional time for "communication among design team participants and to reconciling potential conflicts and trade-offs that involve human-system issues" (ISO, 2010, p. 9).

Under this umbrella, there are a few variations. Participatory ergonomics is a HF & E subdiscipline that focuses on the involvement of users in identifying from the perspective of ergonomics what aspects of their work tasks and environment might affect negatively or positively on the outcome of their work (Vink, Nichols, & Davies, 2005; Wilson, Haines, & Morris, 2005). Haines and her co-authors proposed a framework to categorise what types of users might be involved, how to involve them, the role of the designer in the process and the scope and scale of the project (Haines, Wilson, Vink, & Koningsveld, 2002). Vink and his co-authors demonstrated positive effects for comfort and productivity by using a participatory process (Vink, Koningsveld, & Molenbroek, 2006). Together with others, Broberg (Broberg, Andersen, & Seim, 2011; Hall-Andersen & Broberg, 2014) has proposed using the boundary object theory introduced by Star and Griesemer (1989) to implement participatory ergonomics processes in the use of specific objects. With respect to ship design, Mallam and his co-authors have followed this approach by using general arrangement drawings of a ship to engage with the ship crew in how the layout of an engine room might affect their work tasks and how a better layout could be designed (Mallam, 2016; Mallam & Lundh, 2014; Mallam, Lundh, & MacKinnon, 2016, 2017b).

Van de Merwe and her co-authors (2016) proposed that a design of a ship should begin with an analysis of the needs and experiences of the ship crew, calling this process "Crew-Centred Design" (CCD). The CCD process comes with an online course designed for maritime engineers that introduces HCD principles and their use in the CCD process. The authors refer to the need for maritime engineers to experience the work of the ship crew, but they do not present a specific way for how to implement it and connect it to the ship design process.

2.3.5 Summary

The lack of adoption of HF & E issues and usability-centred design methods by ship designers is a form of critique to HF & E from the maritime engineering community. Critique also comes from practitioners of HCD methods and processes. Giacomin notes that a usability-centred design approach "address[es] well the needs of the users of tools, since tools have predetermined functions" (Giacomin, 2014, p. 608). A number of scholars (e.g Degani, 2004; Gasson, 2003; Suchman, 2007) explain that when interacting with a product, system or service, humans do not generally follow a predefined cognitive plan for which the product, system or service can be optimised. Usability-centred approaches have also been criticised for reducing the scope of the design work to how well a product or system meets requirements, and not necessarily in terms of the experience of the user, which might bring more breadth and depth to the design process (Bannon, 1995a). Bødker and Buur have criticised usability-centred design processes for bringing end-users in too late in the design process, resulting in too small an impact for them (Bødker & Buur, 2002; Buur & Bødker, 2000).

In the next section I review HCD design practices from other design and engineering traditions. I focus specifically on the practices that stem from industrial and interaction design tradition and their application in the maritime domain.

2.4 HCD PROCESSES FROM THE INDUSTRIAL AND INTERACTION DESIGN TRADITIONS

Industrial and interaction designers are increasingly working with design projects in the maritime industry (Lurås, 2016b). Their design tradition derives from several disciplines, such as (obviously) industrial design, HCI, CSCW, workplace studies, participatory design, ethnography applied to design, co-creation and codesign. A number of these disciplines are closely related to HF & E and share principles and methods with them. However, with a specific emphasis on the experience, motivation and participation of the designer and of the users, the industrial and interaction design traditions bring a different take on HCD than usability-centred approaches. A quotation from the industrial designer Henry Dreyfuss (2003, p. 3) illustrates this difference well:

> We bear in mind that the object being worked on is going to be ridden in, sat upon, looked at, talked into, activated, operated, or in some other way used by people individually or en masse.
>
> When the point of contact between the product and the people becomes a point of friction, then the industrial designer has failed.
>
> On the other hand if people are made safer, more comfortable, more eager to purchase, more efficient – or just plain happier – by contact with the product, then the designer has succeeded.

In the rest of this study, I make a distinction between HCD processes which follow this type of perspective and those which follow a usability-centred perspective only. In the next section I present briefly how the industrial and interaction design traditions approach HCD processes.

2.4.1 Relevant design domains

Participatory design introduces the idea that when designers involve users in their design processes, it makes them responsible for defining their role in relation to the other designers and the users they are working with. In Scandinavia, Ehn (1993) and Nygaard (1975) built the foundations for participatory design. Bratteteig and her collaborators produced several syntheses and guidelines for participatory design (Bratteteig, Bødker, Dittrich, Mogensen, & Simonsen, 2012; Bratteteig & Wagner, 2016). Outside Scandinavia, participatory design traces back to the work of Arnstein (1969) and Mumford (1986). For this study, participatory design highlights the responsibility of the designer, his or her motivation and ability to work with and for the end-users of the designed product.

Bødker and Buur integrated these reflections in their practice of user-centred design and usability testing after observing “the lack of cooperation between designers, usability professionals and users, and the weak impact on design caused by the analysis/evaluation bias of usability” (Bødker & Buur, 2002, p. 153). While working on design cases with industrial companies that use complex technology in collaborative situations, Bødker and Buur proposed to focus on the “involvement of usability concerns early in design, [the] concern for actual use rather than what is reproduceable in a lab, and [the] collaboration between the competencies of design and usability” (Buur & Bødker, 2000, p. 297).

Bødker and Buur have introduced a variety of design methods that use different ways to interact with users, or “participants” as they are referred to in the participatory design tradition. They use, for example, methods such as design games, movie making and enacting scenarios (Bødker & Buur, 2002); Buur also worked with theatre (Buur & Friis, 2015; Ryöppy, Lima, & Buur, 2015). A central component to their practice is to design in situ, at the location where participants live and work.

“Ethnography-based methods” are design methods in which the notion of place and field work are central to the design process (Blomberg et al., 2009). The designer acquires a direct experience of the place where users live and work while collecting data about users and their context of use. Blomberg and her co-authors (2009, p. 973) summarise the motivations of introducing ethnographic approaches by their ability to:

1. enhance the working models of developers about the people who will interact with technology solutions and the domains and contexts in which they will do so
2. provide generative tools that support innovation and creativity
3. provide a critical lens for evaluating and prioritizing design ideas
4. serve as guidepost or point of reference for development teams

HCI is one design tradition where ethnography-based methods have been developed (Nova et al., 2015). One of the motivations for introducing such approaches came from the realisation that "the designers and the developers of [HCI] technologies could no longer rely exclusively on their own experiences as a guide for the user requirements of these new systems" (Blomberg et al., 2009, p. 965). This realisation took place in the context of the development of computer technology in the 1980s and 1990s and the possibilities this technology created for new forms of interaction with users, especially in workplaces (Button & Sharrock, 1998; Button, 2012; Hughes et al., 1994). The discipline of CSCW originated with the rise of information network technology and networked computers, such as local area networks and the internet. These technologies created additional opportunities for collaboration and new forms of social interactions (Schmidt & Bannon, 1992). CSCW used disciplines such as cognitive psychology and HF & E to allow for a more structured description of users in their context, the study of work and workplaces (Bannon, 2000; Schmidt, 2000).

For my research, the HCI, CSCW and workplace study traditions highlight the intricacy of the social and technological domains; in other words, technology needs to be understood from the perspective of its use by human operators. Even more importantly, this observation applies to the context in which the technology is designed: ship design, for example, needs to be understood as a context that combines social and technological aspects. While it is a technology-centred design process, a multitude of designers from different perspectives need to work together to pull off the feat of designing such a complex object as a ship (Lurås, 2016b).

Contextual design is an example of an ethnography-based method developed for industrial and interaction designers (Beyer & Holtzblatt, 1998). Contextual design has been developed specifically for organisations that are working on standardised production processes (Beyer, Holtzblatt, & Baker, 2004). In a contextual design process, users are most often referred to as "customers", which implies a commercial aspect (Beyer & Holtzblatt, 1998). Contextual design has been used in a wide variety of applications, including software, hardware, process engineering, consumer product design, manufacturing, automotive and medical equipment design (Holtzblatt & Beyer, n.d.). To my knowledge it has not been used for design projects in the maritime industry. Contextual design is an example of a HCD process that combines participatory and ethnography-based methods. However, it is a process that is intended only for HCD practitioners, and it does not focus on introducing HCD methods into existing processes.

Co-design, or co-creation, builds design processes in which several designers can work together, and work with users. In this case, designers might involve users as "expert[s] of [their] experience" (Sanders & Stappers, 2008, p. 12). Co-creation processes work towards establishing a degree of collaboration that enables the designers to extract, synthesise and inject the users' experiences into the design process. Where co-creation focuses on building up a design process driven by collaboration, collaborative design looks at how to facilitate collaboration in a design process that is not originally intended for it. In that sense I have worked with collaborative design rather than co-creation.

Design offices such as IDEO and schools such as the Stanford d.school have been teaching, communicating and popularising the principles and methods of HCD internationally. They have promoted them under the term "design thinking" for a wide variety of contexts, including business development and business strategy (Brown, 2009; Kelley, 2001). This publicity has contributed to presenting HCD approaches as a type of go-to solution that could handle any type of problem. Norman (2005) and Norman and Verganti (2014) have argued that good design does not need HCD processes, and that HCD processes can even hinder innovation. Another critique is that user needs taken by themselves do not necessarily match up with the needs of the larger system the users are a part of: "it is now becoming apparent that the user-centred design approach cannot address the scale or the complexity of the challenges we face today" (Sanders & Stappers, 2008, p. 10).

In a context like the maritime industry where the perspective is traditionally not human-centred, there is significant potential to include HCD processes without hindering innovation. The observation made by Sanders and Stappers, however, is important to acknowledge because of the linearity of the ship design process. For instance, no matter how well HCD processes and methods might be implemented into the preliminary phases of ship design, there are many design decisions that are made at the moment of building the ship at the ship yard that the ship designers have no control over, and that have a significant impact on the experience of the end-users. Also, ship designers are using off-the-shelf systems in their designs. The impact they can have on the design of these systems is limited to how these systems are integrated into the overall design of the ship.

In summary, and with reference to the research gaps introduced in Section 1.2, the industrial and interaction design traditions bring a perspective and a design methodology that are well suited to address the inclusion and collaboration gaps with a strong emphasis on experiencing user contexts and facilitating collaboration across design participants. The emphasis on responsibility and motivation is also important for sharing these methods with the maritime engineering community. However, the application of such methods is challenging, as Sanders and Stappers observed: "In addition to bringing people into the design process in the ways most conducive to their ability to participate, researchers will need to bring in applicable domain theories in a way that can be handled by the co-design team" (Sanders & Stappers, 2008, p. 14).

This challenge has important implications for the outcome of the design process. Rasmussen and Jensen (2018) refer to "onboarding operational staff" as a common practice in ship design in which, for example, captains are invited to design meetings ashore with ship designers. I argue that having a captain present in a meeting with designers does not guarantee that designers will be able to extract the most relevant information they need for their design process. One reason is that the captain and the designers do not have the same representation of the ship and of the operation of the ship. Another reason is the complexity of the ship operations. As a result, the captain might not know the information the designers need, nor how to share it with the designers, and the designers might not know what information they can obtain from the captain, nor how to ask for the information they need.

The same precaution applies to the other form of onboarding that Rasmussen and Jensen refer to as “onboarding design staff”, when, for example, designers are sent onto a ship. In that case, “onboarding” is a field study performed by designers. As such it needs to be considered as a design activity, backed-up with appropriate methods, and it needs to be anchored in a specific design process. When using field studies for ship design processes, two main challenges arise: first, how to work with the ship crew onboard the ship and enable them to become informants to the ship design process; and second, how to produce design material from this crew interaction that is relevant to the work of the rest of the participants in the ship designers process. I explore these challenges in further detail in the next section.

2.4.2 Field studies in ship design processes

I introduced in Section 2.3.3 a number of publications that make use of field studies on ships. I introduce a few more publications in this section, with a focus on how field studies might contribute to an ongoing design process. This is list is not exhaustive, but it gives an overview of the state of the research in the use of field studies in ship design processes.

Coming from the Ocean Industries Concept Lab at AHO, Nordby and Lurås worked on the design of ship bridges in the Ulstein Bridge Vision and Ulstein Bridge Concept projects. They used field studies to inform the insight collection phase and to test design concepts (Lurås & Nordby, 2014, 2015). Nordby and other collaborators developed a method to collect data about the general arrangement of ships workplaces (Nordby, Komandur, Lange, & Kittilsen, 2011). Lurås developed a field study guide (Lurås, 2015) and a mapping technique for communicating and working with field study insights (Lurås, 2016a). Their combined research addressed the challenges of sharing insights from the field with other team members, the importance of the personal experience of the field and how taking part in a field study contributes to improving design judgement and design decisions in the design process.

Their main contribution is the “design-driven field research model” (Figure 10) which proposes that designers engaged in design activities onboard ships should use the following three design activities: collect data by following a specific field data collection plan; use sketching and prototyping to generate design concepts while onboard the ship and communicate them to the ship crew for an immediate evaluation; and consciously experience what living and working on a ship consists of (Lurås & Nordby, 2014, 2015).

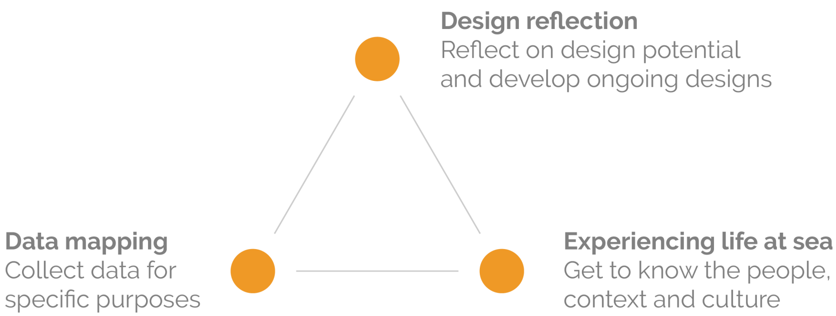

Figure 10: Design-driven field research model, reproduced from Lurås and Nordby (2014).

Lurås and Nordby based their field study process upon a top-down approach (Kujala et al., 2003; Randall, Harper, & Rouncefield, 2007) where the scope of the field study is derived from an analysis of the design process it is informing. To work with the field data, the process uses the collaborative data analysis workshop introduced by Millen (2000) and emphasises data analysis methods that focus on the way data is represented and communicated to a multidisciplinary team (Diggins & Tolmie, 2003).

I used Lurås and Nordby´s approach and methods extensively in my research. I reused, taught and extended the design-driven field research model (see Section 5.3.3). I used Lurås´s layered scenario mapping technique to facilitate collaborative activities such as planning a field study, positioning field study findings and analysing the findings (Lurås, 2016a). Where Lurås and Nordby had a "design-driven" focus on field studies, with field studies as one example of industrial and interaction design activities in an industrial and interaction design process, I chose to have a "field-driven" focus for ship design processes, with field studies as one example of design activities to be combined with other activities in ongoing ship design processes. As such I have focused on the integration of field studies in ship design processes and extended Lurås and Nordby´s work through analysing the needs of ship design processes and ship designers, identifying the design activities that need to be carried out before and after the field study, and reframing the needs that must be introduced to enable the introduction of HCD methods into a domain that is not used to such methods.

There are other examples of published research on the use of field studies in ship design. Also from AHO, Hjelseth used game engines to prototype concepts and to recreate operational scenarios using insights gathered in field studies

(Hjelseth, 2016). This technique enables several users to interact in real time with a scenario, which can be used as an alternative to performing a field study.

With a background in industrial design and design management, Ahola and Murto worked with field studies to document and analyse the experiences of cruise vessel passengers with respect to safety (Ahola & Mugge, 2017; Ahola, Murto, Kujala, & Pitkänen, 2014; Ahola et al., 2018). They made a number of detailed observations on how passengers react to different safety procedures and systems.

Mallam, Lundh and MacKinnon worked with a software prototype that uses a 3D model to visualise the movement and work tasks of ship crews. They conducted several field studies to gather insights during the development process (Mallam, Lundh, & MacKinnon, 2017a; Mallam et al., 2017b). Their software is developed to support ship design processes, so its intended use is by ship designers in their office. The software prototype was tested by naval architecture and ocean engineering master's students from Chalmers using a usability questionnaire.

At the Norwegian University of Science and Technology (NTNU), Rumawas used field studies to analyse the application of HF & E principles on offshore supply ships (Rumawas, 2016). Bjørkli, Øvergård and their colleagues used field studies with the Norwegian Royal Navy to study navigation problems, such as how navigators make decisions, train and learn, and what models can be built to describe these processes (Bjørkli, Øvergård, Røed, & Hoff, 2007; Øvergård, Bjørkli, Røed, & Hoff, 2010). Røed used field studies to study the workplace of different crew members onboard the fast patrol boats of the Norwegian Royal Navy (Røed, 2007). He identified operational problems and proposed design concepts to address them. Bjelland used field studies for the experimental design of power throttles on high-speed crafts and proposed design concepts based on haptic interaction (Bjelland, 2008).

In the Netherlands, the ship design and building company Damen has started to work with industrial designers (de Monchy, 2014; Smit & de Monchy, 2014). They worked on the redesign of a bridge console for a harbour tug. The design process did not include a field study, but it was triggered by feedback from the users of an unsatisfying design. The redesign was based on user input through focus groups and was tested at sea in real conditions during a sea trial.

These examples show the diversity in the use of field studies in design processes, and some alternative methods. Table 3 gives an overview of the presented cases in terms of the design artefact, background of the designers and how the field studies were used in the design process.

This table shows that the backgrounds of the designers are predominantly from HF & E researchers, followed by industrial and interaction designers. There is only one instance of a maritime technology researcher. In terms of the design artefacts, a majority of the cases consist of the design of individual parts of a ship, with several projects focused on the ship bridge. There are no cases in this list where the design of the whole ship was the target of the design process. Such cases exist, however; for example, Lützhöft and Vu refer to full ship design cases of a lifeboat, a service operations vessel and a Pure Car/Truck Carrier (PCTC) vessel (Lützhöft & Vu, 2018). In the presented cases, the use of field studies is balanced between gathering insights at the beginning of the process and testing prototypes towards the end. The former tends to originate from cases of design processes led by industrial designers and interaction designers, while the latter tends to originate from projects led by HF & E researchers.

Table 3

Overview of cases of field studies published in ship design research literature (sorted by designer´s background)

Reference	Design artefact	Designer´s background	Use of field study
(Bjelland, 2008)	Throttle system in high-speed crafts	HF & E research	Insight gathering
(Bjørkli et al., 2007; Øvergård et al., 2010)	(not specified)	HF & E research	Analysis of navigation decision-making and training
(Mallam, Lundh, & MacKinnon, 2017a, 2017b)	Software visualising movements and work tasks on a 3D model	HF & E research	Insight gathering and prototype testing
(Porathe, 2006)	Map system	HF & E research	Testing of functional prototype
(Rumawas, 2016)	(not specified)	HF & E research	Analysis of implementation of HF & E guidelines
(Røed, 2007)	Bridge systems in high-speed crafts	HF & E research	Insight gathering
(J. Gaspar et al., 2016)	Deck layout mooring guidelines and winch console	Maritime technology research and HF & E consultant	Insight gathering and prototype testing
(Ahola & Mugge, 2017; Ahola et al., 2014, 2018)	Interior design and passenger experience	Industrial design	Insight gathering and prototype testing
(Hjelseth, 2016)	Operational scenarios in a game engine	Industrial design	Insight gathering and prototype testing
(Lurås & Nordby, 2014, 2015)	Ship bridge	Industrial and interaction design	Insight gathering and prototype testing
(Smit & de Monchy, 2014)	Bridge console for harbour tug	Industrial design	Testing of functional prototype

2.4.3 Summary

Including end-users in collaborative design processes requires great care. First, the participants in the design process need to be aware of their responsibility as designers. They should ask themselves what role they want to have as designers, and how they want to relate with the users of the products they are designing. If spending time with the ship crew on a ship might lead to better insights into a design process, it needs to be encouraged, because inadequate designs can be identified this way and hopefully fixed, or if not, avoided in the next design project.

Bringing ship designers into the context-of-use of their users is an efficient way to build up this motivation. When ship designers can interact with users in their normal work environment, the designers get a first-hand experience of the situation; to complete the silent observations of the designers, users can provide information about their work tasks and their experiences with performing these tasks even as they are performing the tasks. This method contrasts to the one in which the users would sit around a table in a meeting room and try to explain what they do.

Moving on from motivation to competence, performing this type of field work requires specific methods. The designer's tool kit includes methods originating from the HF & E tradition (e.g. task analysis or think-aloud methods) as well as methods coming from industrial and interaction design (e.g. sketching or prototyping). The designer needs to be aware of the intricacy of the social and technological dimensions of the context he or she is observing. The design process he or she is a part of is also made up of social and technological challenges that the designer needs to be aware of. As such the human-centred approach needs to be applied to both the object of the design, and the design process itself.

To implement such an approach, field work needs to fit with the way existing ship design processes are carried out. This integration raises two main challenges. Before the field study, the needs of the ship designers must align with what can be observed in the field. After the field study, the field observations captured by one part of the team need to be transmitted to the rest of the design team. To address these challenges, I have used a theoretical framework that enabled me to characterise the design activities of both field researchers and ship designers, with the ambition to work out how to connect and combine them in a design process. I present this theoretical framework in the next section.

2.5 TOWARDS A COGNITIVE ANALYSIS OF DESIGN

In this study I use a cognitive approach to break down different design processes and combine them together. The "cognitive" aspect refers to the types of cognitive processes and structures used by designers. This method differs from approaches that focus, for example, on the sociocultural or emotional aspects of design (Visser, 2009).

Coming from the field of cognitive psychology and computer science, Visser proposed a framework where designing is the activity of constructing representations of an artefact (Visser, 2006a, 2006b). Constructing artefact representations can take place alone or collaboratively, inside a design team or in collaboration with external stakeholders, and through verbal, graphical or gestural interactions. The activity of constructing artefact representations takes places through design tasks, or design activities. It can be a prescribed task, or a task that designers define themselves and implement – in short, what designers are doing when they are engaging with a design process.

Representations are operative and goal-oriented. Visser builds upon Bannon´s view that representations are "constructions, which for some purposes, under certain conditions, used by certain people, in certain situations, may be found useful, not true or false" (Bannon, 1995b, p. 67). Visser uses Suchman´s definition that representations are constructed to make things "visible so that they can be seen, talked about, and potentially, manipulated" (Suchman, 1995, p. 63). Visser builds her framework upon a body of work that acknowledges the central role of representations in design, for example, Goldschmidt, who argued that "in no case is there design without representation" (Goldschmidt, 2004, p. 203).

In Visser´s framework, the construction of artefact representations is a "specification activity [that] consists of developing (generating, transforming, and evaluating) representations of the artefact until they are so concrete, detailed, and precise that the resulting representation[s] . . . specify explicitly and completely the implementation of the artefact" (Visser, 2006a, pp. 12–13). In ship design, ship representations include, for example, technical drawings, sketches of ships and CAD models. The 2D general arrangement drawing is the representation that is common to HF & E and naval architecture disciplines (Mallam et al., 2017a), and the one mostly used in meetings to discuss details about the overall ship architecture (Yrjänäinen & Florean, 2018).

Visser (2009) introduced her framework to offer a synthesis between two traditional views on designing. On the one hand, Newell and Simon proposed that designing is a problem-solving activity (Newell & Simon, 1972; Simon, 1973, 1996). On the other hand, Schön proposed that designers engage in a reflective process while designing (Schön, 1983), facilitating a conversation with the materials of a design situation (Schön, 1992). Schön expands Simon and Newell´s notion that problem-solving can be broken down into two stages: problem-setting ("problem structuring" for Simon and Newell) and problem-solving. Schön proposed that through sketching a solution and having a conversation with this sketch, the designer learns more about the problem. Problem-solving and problem-setting are inseparable, and both are required in the process of designing.

Goldschmidt (2008) critiqued Visser´s framework for its too heavy emphasis on the work of software designers, as opposed to studies in architecture and industrial design. In addition, she did not find it relevant for comparing Newell and Simon´s perspectives to Schön´s. Finally, she observed that the material covered by Visser was too broad and reduced Visser´s ability to focus uniquely on the theory of representations. The way I use Visser´s cognitive framework is not directly impacted by this critique. First, current ship design processes do rely extensively on the use of software systems, so I am using Visser´s work in a way that is not affected by its limitations. Second, the benefit of using a synthetic view on design is that it enables the designer to work in a space where different perspectives can cohabit and be combined. For instance, the technology-centred, human-centred, problem-solving and reflective perspectives can be combined. Finally, I do not put to a test Visser´s theory of representations because there is a consensus that representations are indeed fundamental for design (and Goldschmidt agrees with Visser on this), and because I use the concept of representation only as a way to characterise the technology- and human-centred approaches to ship design. In Section 5.3.5, for example, I present ship representations that are technology-centred, human-centred and hybrid. My proposition is that a hybrid representation that combines technology- and human-centred representations might contribute to facilitating the collaboration between the designers who are used to working with one or the other perspective.

The use of a cognitive framework to describe a situation has been also critiqued by Randall, Harper and Rouncefield. In their book about the theory and practice of fieldwork for design (Randall et al., 2007), they critique Vicente´s use of a cognitive work analysis (Vicente, 1999) for focusing only on work tasks. Their critique can be linked to Suchman's work on situated cognition in which she describes how users react to a given situation in a given context (Suchman, 2007, p. 177):

> "the coherence of action is not adequately explained by either preconceived cognitive schema or institutionalized social norms. Rather, the organisation of situated action is an emergent property of the moment-by-moment interactions between actors, and between actors and the environments of their actions."

This critique does not impact my work either because my use of Visser´s cognitive framework is limited to guiding and structuring my analysis of design practices. In addition, the focus on work tasks includes the observation of other dimensions that influence the execution of these work tasks, for example the use of systems, the organisation of work tasks and social interactions. I include a larger discussion about the influence of different theoretical frameworks on observation and analysis in Section 6.3.

Finally, in Visser´s framework, designing is analysed as a human-to-human collaborative activity. This idea enables me to analyse ship design from a human-centred perspective, and to explore its needs for collaboration facilitation. In Chapter 3, I describe in more detail in the research approach that I put together to study the design cases I carried out in the ONSITE project. This approach is based on iteratively building a model of the human-centred, collaborative, field-driven ship design process I argue should be used by designers in the maritime industry. I conclude Chapter 2 with a first iteration of this model.

2.6 A PRELIMINARY MODEL OF HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN SHIP DESIGN

The human-centred, collaborative, field-driven ship design process should include three disciplinary fields: maritime engineering, HF & E and interaction and industrial design. The process should enable designers from these different fields to combine their respective expertise and specialist methods. It should also facilitate collaboration between the designers and their sub-contractors. The process should involve ship end-users in a way that connects their experience to the needs of the design process. These requirements encompass the three identified research gaps of inclusion, collaboration and connection.

The process should be based on field observation and should emphasise it as a fundamental design activity. The observation of ship end-users can be structured using the work tasks of ship end-users and include other components, such as the use of systems, the organisation of work tasks and social interactions. In short, field observation should follow a problem-oriented ethnography, as defined by Lützhöft (2004), with a top-down approach recommended by Kujala (2003), in order to focus on specific parts of a specific context.

The procedure for the field observation and analysis should be built upon the analysis of the ongoing design process that it is supposed to inform, following Lurås and Nordby´s design-driven field research model and guide to field research (Lurås & Nordby, 2014, 2015). For example, the ship design process informed by the field study might follow the principles of the HCD process described in the ISO 9241-210 standard (ISO, 2010) or Andrews's ship architecture synthesis (Andrews, 2003a). In both cases, the field observation and analysis should capture, analyse and report on elements that are compatible with, and relevant to, the design process they inform.

The process should also include collaboration facilitation activities and prototyping activities. It should use temporary representations of artefacts to facilitate their evaluation by end-users and other design participants. Explicit representations of the design process and the contributions of its participants should also be used.

In the next chapter, I present the research approach I have designed to build further iterations of this model. I present the resulting model in the research contributions chapter (Chapter 5) and evaluate the resulting model with respect to this list of requirements in Section 6.1.

3 RESEARCH APPROACH

This chapter presents the iterative model building approach I used to propose a human-centred, collaborative, field-driven design process for ship design, and a framework that integrates this process in current ship design activities. I derived models of the process and the framework from the analysis of cases that I carried out with the industrial partners of the ONSITE project. This approach is visualised in Figure 11 below.

Figure 11: Research process overview.

The iterative model building process consists of four steps:

1. Carrying out a design case. I worked with three design cases, three field studies on ships, conducted with the industrial partners of the ONSITE project.
2. Building a model of the field study process and its integration into a ship design process. This activity actually led to the creation of two models: a model of the process, and a model of its integration in ship design processes.
3. Interpreting or analysing the model in terms of the components it is made of and how it works.
4. A review of a design case, using the model of the field study process to interpret or reinterpret what the design case consisted of.

In the next sections, I describe the rationale for using an iterative model building approach, and the activities supporting the development of models.

3.1 RESEARCH OBJECT

I investigated the introduction of design methods in a design process. The design methods originated from industrial and interaction design and HF & E practices and consisted of collaborative, field-driven, human-centred methods. The design process into which these methods were introduced was the ship design process, a technology-centred process with technology-centred methods and data.

As a result, the object of this study consists of:

- the construction of a model of the process resulting from the introduction of HCD methods in the technology-centred ship design process; and
- an analysis of the model in terms of what it is composed of, how it works and what it theoretically enables one to do.

When compared to current ship design processes, the model enables one to highlight how users and user data are integrated into current ship design processes; this is the first research question of the thesis (RQ 1). The analysis of what the model enables one to do informs the second research question (RQ 2), that is, the benefits of using a new process. The composition of the model (what it is made of) informs the third research question (RQ 3), which is a description of the model resulting from the introduction of HCD methods in ship design. The analysis of how the model works informs the fourth research question (RQ 4), which is how the operational experience of the ship crew might be connected with the design work of the ship design team. The relationship between the object of the study and the research questions is visualised in Figure 12 below.

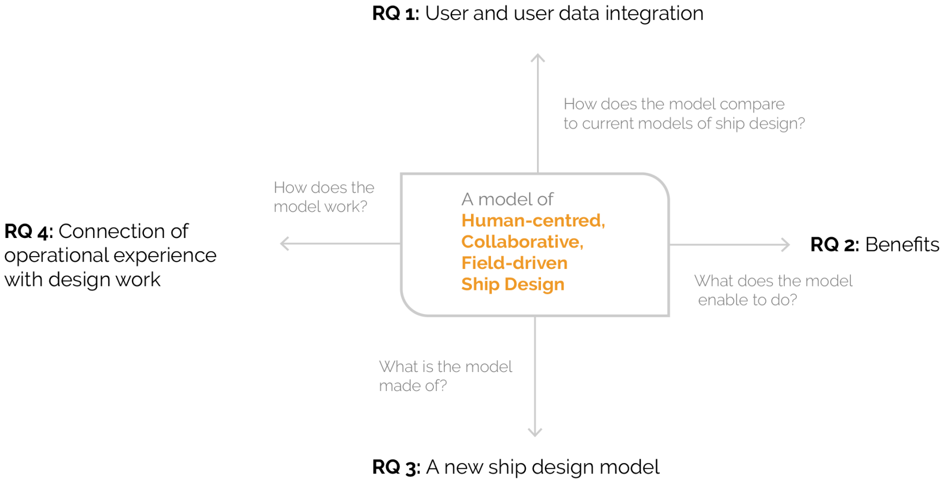

Figure 12: The object of the study and its connection to the research questions.

3.2 RESEARCH CONDITIONS

The study took place through the ONSITE project. ONSITE was funded by three industrial partners and the Norwegian Research Council. ONSITE was led by AHO, and the research was carried out jointly by AHO and NTNU. The objective of ONSITE was to connect ship design and ship operations through the use of field studies. As a result, I worked with three design cases taking place in the context of the commercial and research and development (R&D) activities of the ONSITE partners.

The project participants included discipline experts from the industrial partners Ulstein, PON Power and DNVGL and researchers from AHO and NTNU. Ulstein is a ship design company, PON Power is a company that integrates engine room systems and a sub-contractor with Ulstein. DNVGL is a Classification society and a maritime engineering consultancy company. Altogether, the participants covered the following disciplines:

- maritime engineering disciplines: participants from Ulstein, PON Power and DNVGL (approximately two active participants per company);
- industry and interaction design: project leader at AHO, AHO students; and
- computer science: project researchers at NTNU.

My own background covered maritime engineering, through professional experience. I also had basic notions of computer science from a master's degree in numerical modelling. Prior to working with the ONSITE project, I had worked for two years together with AHO and DNVGL on the use of HCD methods to facilitate collaboration at the consultancy department of DNVGL. Thus, I also had background in HCD methods.

The industrial partners expected to participate in one field study process each. Out of this process, they expected to learn how to implement a field-driven design process. The desired output of the whole ONSITE project was to produce the following:

- a description of how to use field studies in ship design processes,
- a course to teach the use of field studies in ship design processes,
- a software supporting the use of field studies, and
- a model for how the field studies can be better connected with ship design processes.

The ONSITE project created the following conditions for my own research.

- The research was designed to take place through case studies. Each of the three field studies carried out in ONSITE became a case of experimental implementation of human-centred, collaborative, field-driven design in ship design processes.
- Each field study was designed to inform an ongoing design process taking place at the industrial partners' companies. The industrial partners had a commercial interest and the expectation that the research and the field studies would lead to innovation.
- I had a double role in the project: leading each field study and participating in the research informed by the field studies. I was part of a research team at AHO that included design researchers with expertise in industrial and interaction design applied to maritime design processes.

These implications led to the use of the following research protocol for this study.

- The research was based on case study analysis. Each one of the three field studies I conducted is a case informing the overall study.
- The research follows the tradition of research by design, where academic research is informed by design practice, and design practice benefits from the research findings (Findeli 2010). In this study, the object of the research was a design process, and the design practice consisted of the implementation of this process.
- The research was based on a participatory action research model (Whyte 1991), where I was both a participant in the design cases (leading the design cases) and a participant in the analysis of the design cases. The analysis of the design case was based on material produced during the design cases.

3.3 THEORETICAL FRAMEWORKS

Iterative model building took place through a reflection over the design processes I engaged with. My research activities were derived from a positioning of research as design practice, using actual cases as source material.

3.3.1 Design praxeology

The study of design practice and processes of design is an area of research in design referred to as design praxeology (Cross, 1999). It consists of "the study of the processes of design, and the development and application of techniques which aid the designer" (Cross, 1999, p. 6). In my context, I am studying the process of designing ships and the construction of a model which enables maritime engineers, industrial and interaction designers and HF & E experts to work together and combine design methods from their respective design traditions.

3.3.2 Research as design practice

Research as design practice is a methodology for addressing problems in the field of design research, popularised for example by Frayling (1993). The advantage of such an approach is the ability of the researcher to engage in design practice while at the same time exploring research questions (Findeli, 2010). This implies a first-person research setting where the researcher gains access to in-depth, tacit knowledge of a design process through a constant movement between action and reflection (Sevaldson, 2010). Tacit knowledge by definition cannot be explained in words and requires communication through practice (Polanyi, 2009). The first-person research I engaged with consisted of an experimental introduction of new methods into actual design processes.

3.3.3 Case-based research

Stake argued that "case study is not a methodological choice, but a choice of object to be studied" (Stake, 1994, p. 236). In my research, I chose to study the introduction of new design methods in ship design through three cases of the experimental introduction of new design methods in ship design processes. Yin recommends using case study research when the possibility of controlling the events to be studied is limited for the researcher and when the phenomenon to be studied is contemporary and exists in a real-life context (Yin, 2013). In my research, I was not in control of what would happen either during the field studies I conducted or during the workshops I facilitated. Case study research was thus a convenient choice.

The cases that I studied were "instrumental", in the typology proposed by Stake, where "a particular case is examined to provide insight into an issue or refinement of theory. The case is of secondary interest, it plays a supportive role, facilitating our understanding of something else" (Stake, 1994, p. 237). In that sense, my cases provided insight into how human-centred, collaborative, field-driven design methods might be introduced into ship design processes, what they might contribute to and what challenges might arise in this introduction. Taken together, the three cases I analysed consist of a “collective case study” (Stake, 1994, p. 237). Although the scope of each field study was different, the case it constituted was an instance of the same general phenomenon. So, the study of each case was extended to several cases of the same phenomenon.

Stake refers to Smith’s definition of a case as a bounded system (Stake, 1994, p. 236). I used three cases, one for each field study. The boundary of each case follows the boundaries of the field study process described in Publication 3. The field study starts with a workshop where its scope will be agreed upon. The field study ends when the study findings are delivered in a report or in other forms of result dissemination.

Publication 1 (Gernez et al., 2018) gives an example of the type of knowledge I extracted from a case study. Stake (1994, p. 237) argues that a case study offers two types of learning opportunities: “a case study is both the process of learning about the case and the product of our learning”. In my research, learning about the case related to the question of what field studies might contribute to a ship design process. The product of the learning related to the question of how this contribution might take place through a process built for the use of field studies in ship design processes.

3.3.4 Case analysis through model building

The analysis of each case of the introduction of HCD methods in a ship design process took place through two steps. The first step was the construction of a model of the process resulting from the introduction of these methods. As a second step, the model was analysed in terms of what it was made of, how it worked and what it enabled one to do.

My approach to model building followed a hermeneutic approach, where I navigated between individual components of the model and the whole assembled model. This approach is iterative; the iterations took place within one case and its analysis as well as across the three cases taken together. As such, this process relates to what Yin refers to as iterative explanation building (Yin, 2013), where individual components of the model are identified in each case and are compared from case to case.

The components of the model I have been assembling were derived from two sets of theories. The first set was a combination of different theories which seemed relevant at the beginning of the ONSITE project. For example, I used mapping techniques originating from service design (see Section 3.4.2). Later in the project, I chose to work with theories related to cognitive design studies, for instance Visser’s cognitive framework for design. In this type of theoretical framework, I was interested in finding process model components such as process timeline, process steps, design participants and design contributions. Because the research in ONSITE took place in collaboration with computer scientists, I also used some notions from computer science to model components such as input and output of process steps, or input and output exchanged between design participants. Finally, from theories related to the use of ethnographical methods in design, I used notions such as observer, informant, context of use and context of observation.

In the second phase, I consolidated this set of theories by using Visser's cognitive viewpoint on design. Visser uses this framework to study "the actual cognitive activity implemented by designers during their work on professional design projects" (Visser, 2006b, p. 3). I used this framework to describe which activities users of the design process engaged with, including both ship designers and ship end-users. In this way, I reused all the model components of the first phase and included them in one unified group. To this group I added the components of design activities and work tasks with which users engaged in their work.

3.3.5 Participatory action research in the workplace

The first-person research setting I engaged with enabled me to assume different roles:

- a generator of the research material by leading three field studies and documenting each field study process;
- an observer of my own actions through engaging in reflective activities;
- an observer of others, through direct observation, conversations and informal interviews during meetings, workshops and field work (here, "others" refers to all the participants in the ONSITE project and its different informants); and
- a co-researcher, through my contribution to research about the field study process, the course and supporting software, in collaboration with the other researchers of ONSITE.

This type of research approach is similar to a participatory action research approach, with the idea of basing research on field experiments (Gustavsen, 2001). Field experiments refer here to the experimental introduction of new methods in ship design processes; the phrase does not refer to the field-driven design methods which were introduced.

Historically, participatory action research has been used to deal with change in the workplace, with the ambition to use participation as a way to facilitate the acceptation of change (Pasmore, 2001). Although the study of the acceptation of change is not one of the objectives of this study, the ambition was that introducing new methods in actual cases of ship design might support the adoption of these methods. Participatory action research in the context of the workplace is closely related to sociotechnical systems theory (Pasmore, 2001), with particular attention paid to work tasks and their interdependencies. This connects back to Visser's cognitive framework and its use in describing the work of designers.

3.4 RESEARCH ACTIVITIES

The research activities were derived from the design activities I engaged in when carrying out field studies with the industrial partners, and their analysis through iterative model building.

3.4.1 Model building

As shown in Figure 11 in the beginning of this chapter, I followed a hermeneutic approach which consisted of two types of processes:

- a synthesis process, where I built models from the components I identified in the design cases; and
- an analysis process, where I took apart the assembled model and looked again at the individual components.

This activity was iterative. Publication 1 (Gernez et al., 2018) shows an example of a design case, with a first analysis of its contents. It describes a first model of a ship design process which includes human-centred, collaborative, field-driven design methods. It examines which design activities were performed in what sequence and what they contributed to in the design process. This case is based on Field Study #1.

After presenting this first iteration of a process model, Publication 1 concludes with a first glimpse of the integration model. This model is concerned with how the field study fits into the ship design process in terms of how human- and technology-centred perspectives can be connected. The model is described in detail in Publication 2 (Gernez, 2019), with an analysis of its structure and what it theoretically enables one to do.

Publication 3 (Gernez & Nordby, in press-b) presents another iteration of the process model by analysing which activities need to take place, how they might be carried out and what data is produced as input to/output from these activities. Publication 4 (Gernez & Nordby, in press-a) examines how this process might be taught to design students.

The synthesis-analysis activity was carried out differently for the process model and the integration model. For the process model, the synthesis–analysis focused on exploring the relation between how a field study would unfold in real life and how it could be generalised into a process. Before starting each field study, I defined the main steps I wanted the study to go through, and I tried to lead the study accordingly. After a field study was concluded, I analysed how each step took place, what activities were carried out, what the contribution of each activity was and what my experience of each activity was. This process and its outcome are described in Publications 1 and 3.

Each field study informed a different design process and had a different scope, so the findings from each study were generalised at a level of abstraction consisting of the field study process steps, tasks, input/output data and representations. In Figure 13, I show an example of synthesis–analysis for the process model with an early mapping of the field study process. Mapping is one of several design activities I combined to help me in the synthesis–analysis process. Mapping and the other activities are described in detail in Section 3.4.2 of this chapter.

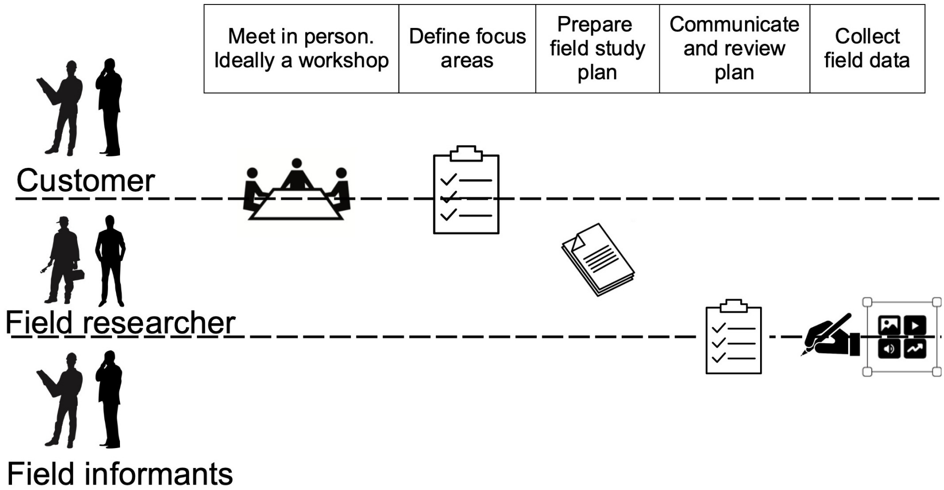

Figure 13: Early example of field study process mapping. Deliverables are represented with symbols, and their location indicates who is supposed to produce them, and when.

For the integration model, the synthesis–analysis focused on exploring the relation between the knowledge generated about a ship during a field study and the knowledge used in current ship design processes. Because these current processes do not include the observation of end-users working on the ship, there was a need to first propose a model that described the work of ship end-users. This is what I refer to as the human-centred perspective on ship operations. The next phase consisted in connecting this model with what ship design processes actually dealt with, which I modelled as the architecture of the ship. This process is described in Publication 2.

In Figure 14, I show an early iteration of the integration model during the analysis phase. The model consisted of three concept categories (the orange, green and blue circles) structured as a Venn diagram. The three categories represented ship operation, ship architecture and ship design processes. In that case, I used a data set I obtained from a design workshop organised by the Ulstein ship design company, in which I did not participate. The data consisted of pictures of whiteboard and paper drawings produced by the workshop participants as well as a report from a short field study one participant had conducted before the workshop, onboard a ship berthed in the harbour. When placing data on the circles, I realised that these three concept categories and their organisation as a Venn diagram did not allow structuring of the information contained in the data in a way which would support the generation and evaluation of design propositions. I used these observations to modify the model by adjusting the concept categories and their organisation, resulting in the framework described in Publication 2.

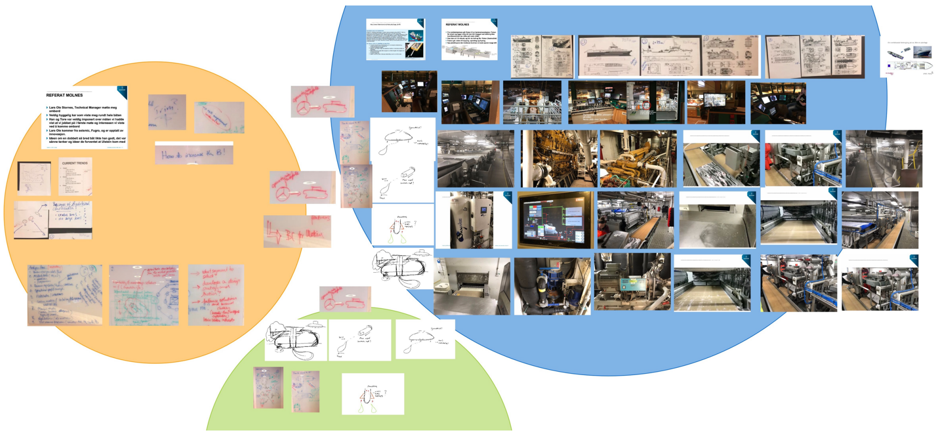

Figure 14: Analysis of an early version of the integration model by placing data on concept categories (the data is intentionally not readable for confidentiality reasons). The three circles represent a Venn diagram: Ship design process (Yellow), Ship operation (Green), Ship architecture (Blue).

3.4.2 Activities supporting model building

I engaged with a combination of individual, collaborative and reflective activities in an approach similar to what some authors refer to as “bricolage” (Denzin & Lincoln, 1994). This approach enabled me to combine the activities I engaged in with the activities taking place in the ONSITE project, which were often collaborative activities occurring in a multidisciplinary setting. This enabled a form of triangulation in two ways described by Stake in his presentation of case study analysis (Stake, 1994, p. 241). The first is “a process of using multiple perceptions to clarify meaning, verifying the repeatability of an observation or interpretation”, and the second is a way to clarify meaning “by identifying different ways the phenomenon is being seen”. This resonated well with the view of designing as a construction of artefact representations; it exposed me to human-centred and technology-centred representations of the ship and the ship design process.

Collaborative activities included the following:

- project meetings, which involved me, my PhD supervisor and computer scientists from NTNU;
- ONSITE board seminars with the industrial partners of ONSITE;
- student projects where industrial and interaction design students were hired in ONSITE to work on specific tasks; and
- student courses – 10 days in March 2017 and March 2018.

Engaging with these activities stimulated my own reflective activities. Reflective activities are important, because they enable a designer or a design team to work creatively and critically with the design material generated through a design case (Schön, 1983). The designer or the design team work concurrently on the analysis of a problem and on the generation of adequate solutions (Buxton, 2007).

Process mapping

The first activity I used was process mapping; I used it in two ways. In the prospective way, I would map a forthcoming field study to plan for its implementation. In a retrospective way, I would unpack my experience of a field study by mapping what activities took place and how. To do this, I used a mapping technique I developed prior to my PhD studies (Gernez et al., 2014). The mapping technique was inspired by service design mapping techniques, such as service blueprint mapping (Shostack, 1982) or customer journey mapping (Følstad, Kvale, & Halvorsrud, 2014; Polaine, Løvlie, & Reason, 2013). These methods were originally developed by service design practitioners to visualise and analyse the different experiences of individuals who interact to deliver a service. Using this technique enabled me to produce human-centred mappings of the processes I engaged with and also showed how different participants engaged with that process. Figure 15 is an example of the first mapping I made, about PON Power's engine system integration process, in order to plan Field Study #1.

Sketching

I used sketching on paper as an individual reflective activity as well as a support for conversations with other project members. In larger group settings, I used whiteboard sketching, for instance during meetings with the computer scientists from NTNU. Figure 16 is a sample of paper sketch that contains examples of information objects used in the field study process, for example observation (OBS in the figure) of a task (TASK) carried out by an operator (operator) in a location onboard a ship (LOCATION). Figure 17 is an example of whiteboard sketch showing discussions related to modelling an observation as a data object and associating it with media (photos and videos which illustrate the observation).

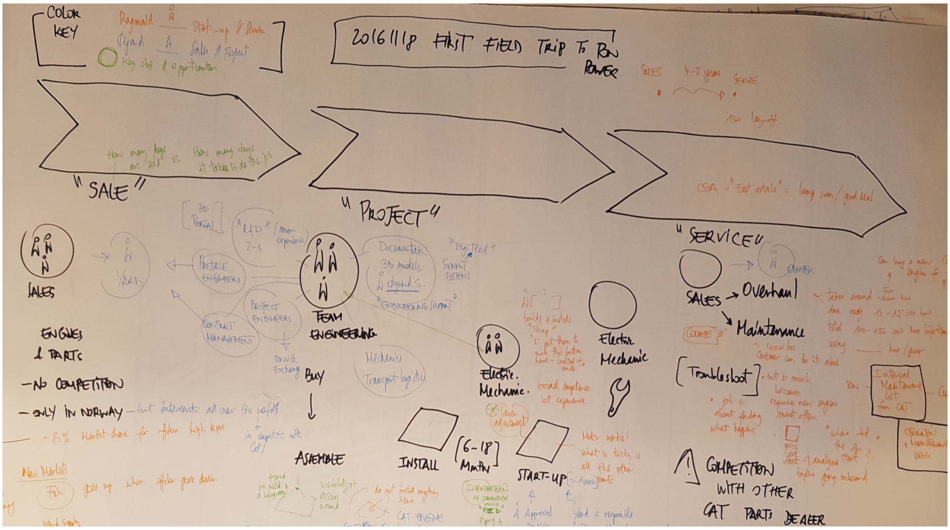

Figure 15: Example of process mapping.

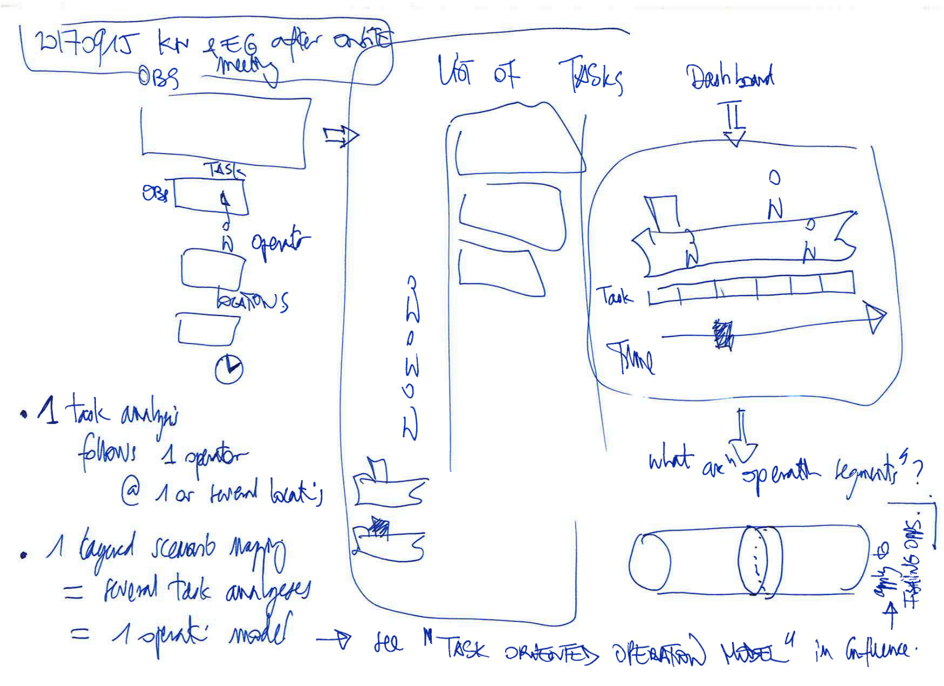

Figure 16: Example of paper sketch used for individual reflection.

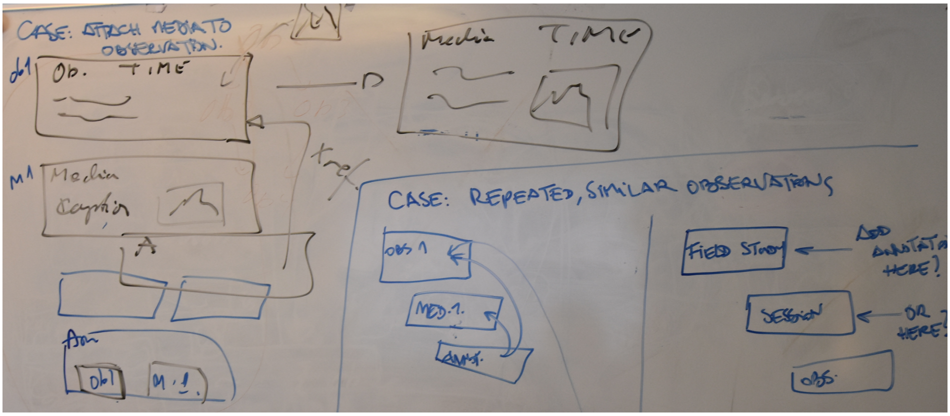

Figure 17: Example of whiteboard sketch used in group reflection.

Collaborative writing

I worked with collaborative writing to complement the project meetings with the computer scientists from NTNU. The discussions and whiteboard sketches produced during the meetings were used to inform textual descriptions of the processes and objects we were working with. To continue the discussions about the textual descriptions, we used a project wiki which supported features such as commenting, hyperlinking and diagramming. Using the wiki, we also wrote academic papers collaboratively (Nordby et al., in press; Schaathun et al., unpublished manuscript, 2017). A screenshot of a page from the project wiki is shown in Figure 18 below. The different topics we collectively worked with are listed on the left part of the screen interface. The screenshot shows an early draft of the description of the field study process.

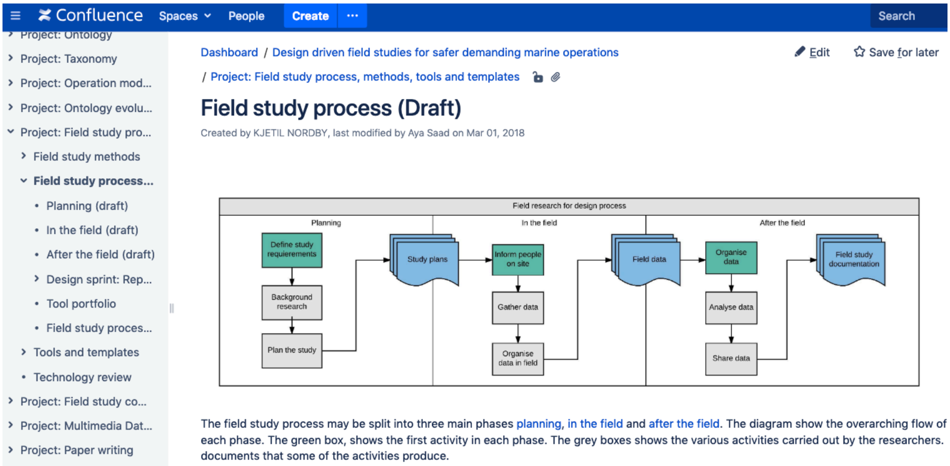

Figure 18: Screenshot of the user interface of the project wiki.

In my individual research, collaborative writing enabled me to accurately describe and analyse personal reflections and assemble them into text descriptions. These were used as support for presentations, course material and academic publication.

Seminar presentations

Seminar presentations were an important activity, where the status of the different research packages of the ONSITE project were presented to the board of the project every six months or so. In these seminars, I would present the status of the field studies I conducted and what findings came out of the field studies as well as the status of the models I derived from the field study cases. The board members represented each company and university involved. The discussions consisted of the company representatives commenting upon what in the presented research was most relevant to their work, how it was relevant and what directions they would like the research to take in the next steps of the project. In return, this contributed to my research by helping me prioritise what seemed to be most important for the actual practice of the designers working with each company involved in ONSITE. I did not record the conversations nor analyse their content in detail. Rather, the data I collected from these presentations consisted of my own notes of the discussions, and I compared my own notes with the notes taken by my supervisor.

Visualisation

I hired design students from AHO to help me visualise what I worked with. This was initially intended simply as support for communicating my research more clearly to the ONSITE partners. The process of visualising was in itself a useful reflective activity, because I needed to explain the content of my sketches to the students who were visualising them. Then I could benefit from their reflections about the ideas conveyed in my sketches, and reflect upon how they proposed to visualise my ideas.

One example of visualisation is the work with use scenarios for the software built to support the use of field studies in ship design processes. When the data architecture and software prototype became functional, I worked with the same group of researchers and two interaction design students from AHO on prototyping use scenarios. The use scenarios described the conditions in which the software would be used, i.e. who would use it, at what step of the field study process they would use it, whether they would use it alone or collaboratively and in what type of working environment, using what type of interface. This activity helped to determine whether the functionalities included in the software enabled one to use it (theoretically) in the field study and to see what missing functionalities would be required.

An example of a use scenario is given in Figure 19. In this scenario, the software is used to facilitate a collaborative data analysis workshop in a meeting room. We used this type of scenario prototyping to derive software requirements such as the following.

- The software should be able to assist in producing presentation material in a fast, simple manner.
- The user interface should take advantage of the standard presence of a large screen with high resolution in meeting rooms.
- Workshop participants should be able to access the presentation material on their own computers or tablets and share their observations and reflections directly into the software.
- This type of additional observations and reflections generated during the workshop would need to be added to the initial pool of field observations and reflections.

Figure 19: Example of visualisation – a prototype of use scenario for a collaborative data analysis workshop after a field study.

Teaching

I was invited to be a teaching assistant for a course for AHO design students on field study-driven design, in March 2017. For the next iteration of the course, one year later in March 2018, I became the leader of the course. This teaching responsibility enabled me to work with an approach that matched the model building approach:

- building a description of human-centred, collaborative, field-driven design processes that is clear and understandable for the students; and
- designing learning activities that enable the students to experience the use of the field-driven design process.

The design and evaluation of the course´s learning activities is described in detail in Publication 4 (Gernez & Nordby, in press-a). Although the course was held for design students, it provided me with a basis which could be expanded upon for different audiences, for instance maritime engineers. I tested this approach briefly by organising a one-day maritime engineers' workshop for employees of one industrial partner of ONSITE who were going to conduct field studies on their own. I also coached a group of three maritime engineers working for another industrial partner in ONSITE in carrying out a field study; I did this by accompanying them on a field study and leading workshops before, during and after the study.

3.5 LIMITATIONS OF THE RESEARCH APPROACH

The research approach is a result of the conditions framed by the ONSITE project and the focus on a specific object of research, as a part of ONSITE. In this section, I focus on how the selected research approach relates to the quality of data collection and analysis activities. In Chapter 6, I discuss the quality of the research in terms of its originality, solidity and relevance from the perspective of the ONSITE project and its contributions.

The main source for data was the three cases of field studies carried out in ONSITE. Each field study produced data about how a field study is carried out on the field, how it can be planned so that it connects with an ongoing design process and how it can be followed up on so that it actually connects with the ongoing design process. The central part of the data I collected took the form of notes that contained observations and reflections generated before, during and after field studies. Most observations and reflection were my own, but they were also supplemented with those of other participants in the ONSITE project. The additional data included notes from other participants in the project seminars. I had access to photos taken by Ulstein ship designers in an internal design workshop, which I used as input to a model building iteration (Figure 14). I also used concepts and sketches produced by the AHO design students hired in ONSITE.

The amount of data that can be collected and processed in a research approach based on the analysis of cases is conditioned by the number of cases and the conditions in which the data is collected. My research is based upon only three cases; this potential limitation is compensated by the variety of the cases, their duration and the level of access I enjoyed. Each field study took place in a different context and connected to a different type of ongoing design process, in a different way and at a different phase of the process. In each case I was in direct contact with three key stakeholders: the designers engaged in the ongoing process, their end-users and the people higher up in the organisation to whom the designers were reporting. I was in contact with these stakeholders during the whole duration, from the initiation of each field study, its planning, execution and follow-up. The three cases were concurrent, and each case lasted between 18 and 24 months, which allowed each ONSITE partner to address the outcomes of the field studies (for example findings and proposed innovation concepts).

Direct access enabled me to collect first-hand data, and the duration of each case allowed me to keep this direct access window open for a long time. The combination of direct access and case duration generated a basis for gathering data of good quality for the purposes of this study. My double role as the main facilitator of the field studies and follow-up workshops as well as the lead researcher of each case meant that there was a limit to what data I could collect at any moment. I focused on collecting data related to the ongoing cases during the field studies and the follow-up workshops. During the rest of the time, I focused on the analysis of the generated data and worked with iterative model building.

In the process of building models based on data from design cases, data collection has been impacted by my design competence and data analysis has been impacted by my modelling experience. With an education background in numerical and mathematical modelling, I felt the most comfortable with the modelling activities. In this domain I benefitted from collaboration with the computer science researchers from NTNU. My experience with design processes did not come from formal education, but from participating in design and innovation projects such as DNVGL innovation projects (DNVGL, 2013; Svensen, 2013) and an international collaborative project on the design of open source sailing drones (Gernez et al., 2012). I benefitted from working with the project leader of ONSITE, who is an experienced industrial and interaction designer, with several design students from AHO, and the ship designers engaged in ONSITE cases.

The quality of data collection and analysis has been strengthened through the collaborative aspect of the research, both in terms of complementary competences and in terms of the multiplication of analytic lenses through which my research was interpreted. An example of an activity supporting this second aspect of multidisciplinary work is the use of collaborative data analysis workshops, which are designed to reduce subjective biases (Millen, 2000). Visualisation activities such as sketching and mapping enabled us to externalise and communicate individual perspectives, especially in group settings such as project meetings, workshops and seminars. Finally, model building based on data from design cases has been iterative, so that I have had the opportunity to adjust the type of data required from one iteration to the next.

In conclusion, the main limitations of my research approach lie in my personal design competence and the need to combine data collection and analysis simultaneously. Through clearly delimitated design cases for which I produced regular deliverables to the industrial partners, and through repeated collaborative workshops and meetings, I followed a systematic approach to data analysis and collection, balancing the time spent on accumulating evidence and on analysing it. Yin (2013) recommends such a research approach in order to progress with confidence in the research process. Such an approach is also considered thorough by Archer (1995), with its emphasis on a systematic and consistent protocol, and its contribution towards unambiguous knowledge transmission. The efforts to mitigate my personal subjective bias through collaborative and multidisciplinary activities are complemented by knowledge transmission activities such as training and coaching on performing field studies, by the field study course at AHO and by carrying out field studies with industrial partners. Academic publishing is another example of an activity that brings thoroughness to a research approach. The main results from the four publications included in this study are presented in detail in the next chapter.

4 RESEARCH RESULTS

This study is built upon four publications. In this chapter I review the individual results of each publication. The first one is a case that shows the experimental implementation of human-centred, collaborative, field-driven design methods for the design of ship engine rooms (Gernez et al., 2018). The second publication describes a framework in which field studies are combined with other design activities to connect the design of the architecture of the ship with the design of the operation of the ship (Gernez, 2019). Based on the experiences from all the field study cases carried out in ONSITE, Publication 3 presents a generic model of a human-centred, collaborative, field-driven design process (Gernez & Nordby, in press-b). Finally, I present a course designed to teach the use of field studies in design processes in the maritime industry (Gernez & Nordby, in press-a).

4.1 PUBLICATION 1

Gernez, E., Nordby, K., Seim, Ø., Brett, P. O., & Hauge, R. (2018). Human-Centered, Collaborative, Field-driven Design - A Case Study. In P. Kujala & L. Lu (Eds.), *IMDC 2018: 13th International Marine Design Conference* (Vol. 1, pp. 291–305). London, UK: CRC Press / Balkema.

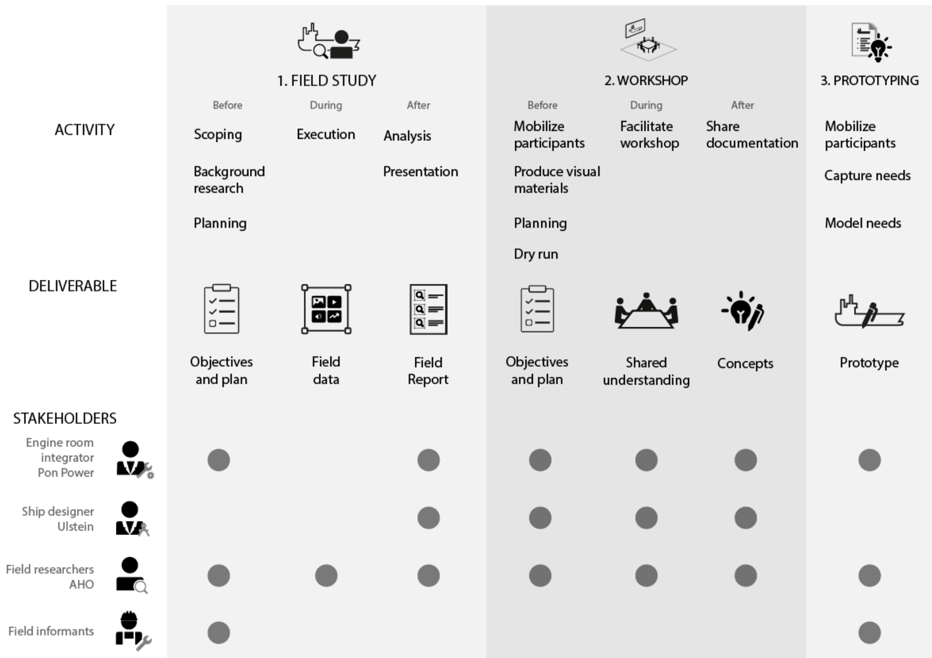

Figure 20: The design process reported in the publication. This figure also shows how the early process mapping (represented in Figure 13) has evolved.

In this co-authored publication I was the main contributor in data collection, analysis and writing. Together with the co-authors, I explored the implementation and impact of field studies in a collaborative design process between a ship designer and a ship engine room integrator, both participants in ONSITE (Figure 20). The publication presented a detailed report of the design process we used with a description of how each activity was performed and what it produced. The publication also presented some reflections and feedback from the participants.

The participants in this case were:

- field informants: a ship captain and his crew onboard a Platform Supply Vessel (PSV), as well as a mechanic from PON Power doing service interventions on ships (including this particular vessel, but not only),
- designers: a technical project manager from PON Power and three maritime engineers from Ulstein, two of them working at the preliminary ship design phase and one at the detailed engineering phase. In Figure 20, I grouped the participants per company: “engine room” integrator refers to all the participants from PON Power, “ship designer” refers to all the participants from Ulstein; and
- field researchers: I was the lead field researcher and carried out the field study alone. A second field researcher (my PhD supervisor) helped me with the analysis of the field data.

The case consisted of a field study onboard a PSV, followed by two workshops. In the first workshop, we presented the preliminary results of the field study to the PON Power representatives who initiated the study. In the second workshop, we explored the collaboration between PON Power and Ulstein. That workshop was followed by a prototyping session in which we filmed a mechanic from PON Power performing service interventions.

To analyse the case material, we used the service design mapping technique described in Section 3.4.2 and a separate publication (Gernez et al., 2014) to compare the approach used in the case with a generic ship design process.

4.1.1 Main findings

1. This case showed that it was possible to involve end-users in the design process through the use of a field study in which their experience of using the engine room was documented.

2. The subsequent analysis of the field data carried out in the collaborative analysis workshops demonstrated the value and relevance of using the field study methodology as a HCD method for ship design processes. The analysis of the end-users’ experiences showed the need for a design intervention, which resulted in a collaborative data analysis workshop between the engine room integrator and the ship designer.

3. The workshop enabled the participants from the ship design company and the engine room integration company to shift their focus from the design of an engine room to the design of a workplace for engine room operators. This shift enabled the creation of a collaborative definition of human-centred needs and requirements for the operation of engine rooms.

4. The workshop helped to organise a follow-up prototyping session in which we worked with a concept for capturing and representing human-centred needs and requirements for the operation of engine rooms in a 3D CAD model. The prototyping session showed that data from scenarios observed during a field study could be re-enacted by a service mechanic and recorded in video as an input to the 3D CAD model. This session also enabled a 3D CAD modelling engineer, a building supervisor, and a service mechanic to work together and share their perspectives and experiences, which is not usually the case in a traditional design process.

4.2 PUBLICATION 2

Gernez, E. (2019). Connecting Ship Operation and Ship Architecture in Ship Design Processes. *Journal of Ship Production and Design*, *35*(1), 88–101.

This publication considers the consequences of applying a HCD perspective to ship design. When end-users inform the design process with their knowledge and experience of operating the ship, how to help designers integrate user experience data into technology-centred ship design processes? How to make this integration a design activity that fits naturally into the ship design process? To address this problem, I developed the Operation-Architecture (OPAR) framework, which distinguishes and connects human-centred ship operational requirements with technology-centred ship architectural solutions (Figure 21).

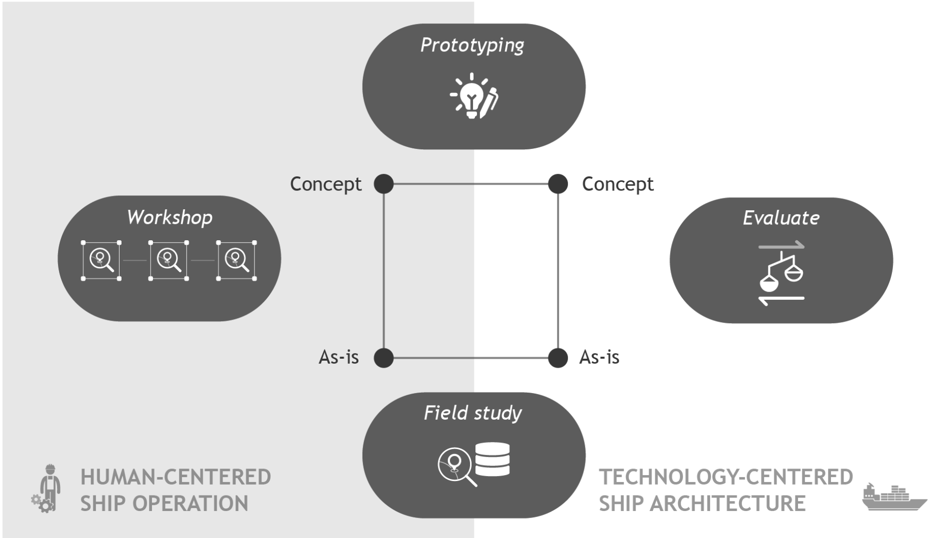

Figure 21: The Operation-Architecture (OPAR) framework, as presented in Publication 2.

The study was based on case material from the three field studies carried out in ONSITE. The OPAR framework is based on the problem-solution co-evolution model originally introduced by Maher, Poon and Tang (1996; 2003). This model views a design process as a concurrent exploration of problems and solutions. With OPAR, I model the ship design process as a concurrent exploration of the operation of the ship (how the ship is used) together with the architecture of the ship (what the ship is made of).

I model the ship operations as the combination of work tasks carried out by the ship crew when engaged in the operation of the ship. I model the ship architecture as the combination of the systems that make up the ship. For OPAR, I place the human-centred representation of the ship operations next to the technology-centred representation of the ship, and propose design activities that connect these two representations. To model the iterative nature of the design process, I add another axis that contains the design activities related to the generation and evaluation of concepts that combine ship operations and architecture.

4.2.1 Main findings

1. By reviewing a large set of published ship design processes, I observed that fewer than half of the published design processes explicitly referred to the operation of ships, and only one did so from a human-centred perspective.

2. The design methods that are integrated in the OPAR framework come from different domains: maritime engineering (e.g. 3D CAD modelling), HF & E (e.g. task analysis), and industrial and interaction design methods such as collaborative

workshops, sketching, and prototyping activities. The field study observation and analysis methods originate from a combination of HF & E and industrial and interaction design disciplines, following Lurås and Nordby´s (2014) design-driven field research model.

3. The use of the problem-solution co-evolution model proposed by Maher, Poon and Tang (1996; 2003) highlights the need for design activities that focus on the definition and exploration of the operational and architectural spaces and that generate connections between the two spaces.

4. Referring to the analysis of design creativity carried out by Dorst and Cross (2001), who use Maher´s model, the activities that generate connections between the operational and architectural spaces are fundamental to stimulate the creativity and expertise of participants in the ship design processes.

4.3 PUBLICATION 3

Gernez, E., & Nordby, K. (in press-b). Implementing Field Research in Ship Design. *Transactions of the Royal Institution of Naval Architects, 158*(C1).

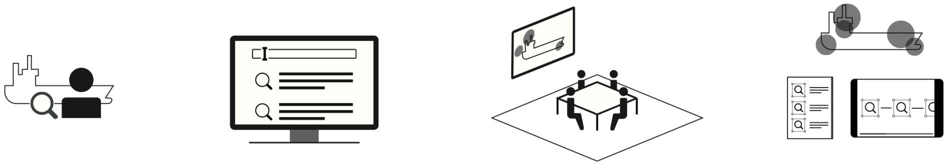

Figure 22: The ONSITE field study process in 4 steps: field study, data entry and analysis, collaborative data analysis workshop and dissemination.

In this co-authored publication we updated a draft of the process initially designed by Kjetil Nordby and Sigrun Lurås. We present a four-step process based on the experimental introduction of human-centred, collaborative, field-driven design methods in the three field study cases of ONSITE (Figure 22). Using an analysis similar to a task analysis, we present a detailed description of the process. We describe what tasks need to be performed at each step, what data is generated by each task, and how to use the data to carry out the next steps in the process. Based on this analysis and our experience, we establish requirements for the efficiency and effectiveness of the process. We discuss how the process addresses these requirements.

4.3.1 Main findings

1. The four-step process is designed to enable the following requirements:

- capture the needs and requirements of the ship end-users,

- connect the end-user needs and requirements with the safety and efficiency of the ship operations, and
- enable the generation of innovative concepts.

2. The breakdown of the process helps one to explore the design of software built to support the implementation of the process. One example of the requirements is to support the collection and modification of all data types produced throughout the process, at the data entry, data analysis, and production of reporting formats for the workshop and dissemination phases. These questions are explored in more detail in three other publications not included in this thesis (Nordby et al., in press; Schaathun et al., unpublished manuscript; Schaathun, Tran, Tollefsen, & Gernez, 2017).

4.4 PUBLICATION 4

Gernez, E., & Nordby, K. (in press-a). A 10-day Course to Plan and Execute Field Studies for Maritime Design Processes. *Transactions of the Royal Institution of Naval Architects, 158*(C1).

This publication presents a course that teaches design students at AHO how to use field studies for maritime design processes. The course is a part of the students´ education in design, in which they can apply human-centred methods in a wide array of industries. In this co-authored publication I was the main contributor in data collection, analysis and writing. The course content and structure has been produced collaboratively by Snorre Hjelseth, Sigrun Lurås, Kjetil Nordby and myself.

The course lasts for 10 days (Figure 23). After three days of introductory lectures, the students are given the design brief to “improve user experiences onboard a ship.” They chose a group of users on a ship and work with them in the field study. They analyse the data individually and in groups in a workshop, and deliver a report with their observations, analyses, proposed concepts, and an evaluation of how the concepts address the problems they have observed and analysed.

During the 2017 edition of the course, the students were asked to write down their experience of the course, and this data was used to evaluate how the learning objectives were met. Writing down and submitting their experience in the course is a part of the course assignment because it is a self-reflective activity for the students, which contributes to their assimilation of the field study process.

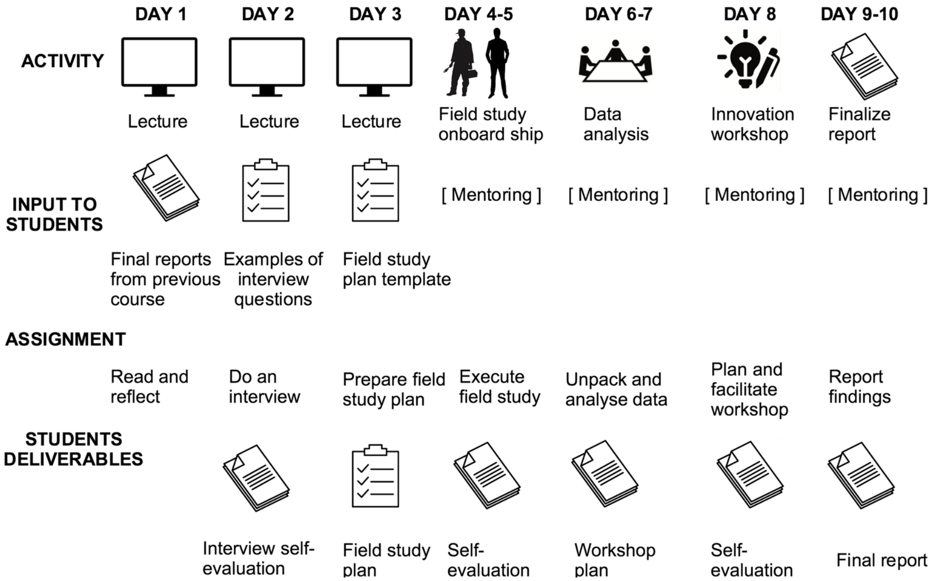

Figure 23: Course structure overview.

4.4.1 Main findings

The analysis of the students´ experience of the course shows that they identified challenges that are common to the practice of field studies (with regards to challenges identified in the literature and to our own experience). This challenge identification was interpreted as evidence that the students had started to acquire the basics of the practice of field study methodology and validates the structure and content of the course.

4.5 SUMMARY

When taken collectively, the research results of each publication show one way to apply a human-centred, collaborative, field-driven design process in ship design processes. A model to navigate the gaps between human-centred and technology-centred perspectives on design is derived from the experience of using this process.

In the next chapter, I explore in more details what these results bring to the fields of ship design and HCD.

5 RESEARCH CONTRIBUTIONS

In Chapter 2, I documented the lack of participation of ship end-users to the design process, as well as a lack of facilitation of the collaboration between the participants to the design process. The first contribution of this study is to introduce design activities that result in a human-centred, collaborative, field-driven methods in ship design process. The second contribution is a framework that enables to implement such a process, by supporting the use of different types of design activities. The central design activity in this framework is the use of field studies and subsequent collaborative data analysis workshops. Although this type of activity has been introduced before in ship design processes, there is a lack of research on how to connect the experiences of ship end-users with the needs of designers. The third contribution of this study is an analysis of this end-user – designer connection.

5.1 CONTRIBUTION 1: INTRODUCING HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN METHODS IN SHIP DESIGN

The introduction of human-centred, collaborative, field-driven design methods in the design of ships results in a process that is human-centred, as opposed to technology-centred. The object of attention becomes the users of the ship, and their use of the ship. The participants to the ship design process also become an object of attention. Shifting the object of attention justifies the need for an increased focus on collaborative activities in the design process. Facilitating for end-user participation and design collaboration across discipline domains has the potential to improve the experience of the participants to the design process, and the resulting outcome of the design process: the ship, and its operation.

5.1.1 Reframing ship design processes towards a human-centred perspective

The reframing of the ship design process is actually a prerequisite before being able to introduce HCD methods in an otherwise technology-centred design process. To do so, I mapped a generic ship design process along a timeline, broke it down into steps, visualised the participants, and showed what they contribute to the process, both alone and collaboratively. The result is illustrated in Figure 24.

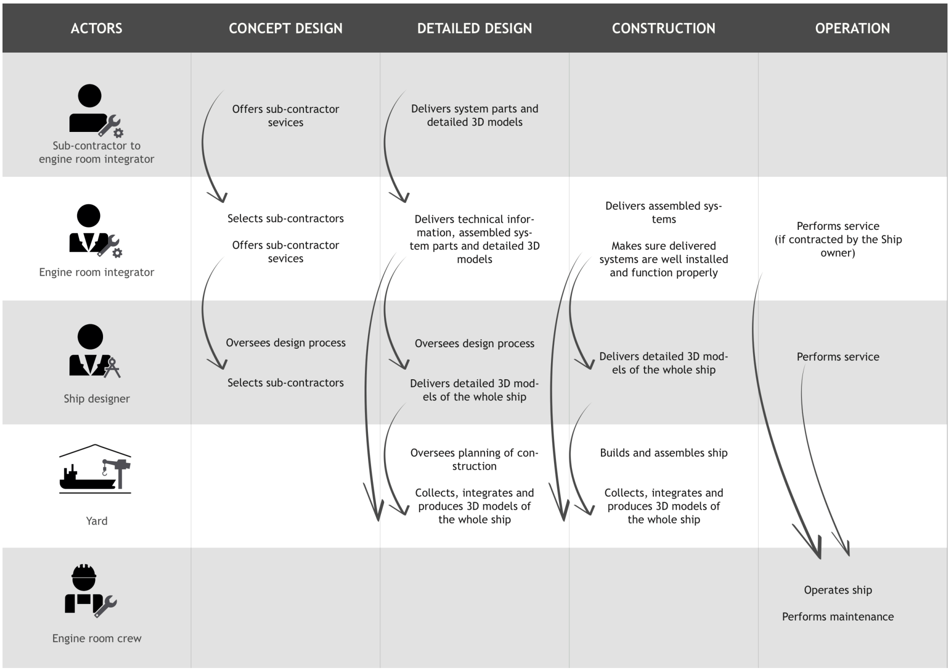

Figure 24: Human-centred mapping of a generic ship design process, reproduced from Publication 1 (Gernez et al. 2018).

The main observation from this mapping is that the end-users are not involved before the last step of the process. In addition, as observed in Publication 1, this mapping shows the density of the interactions among participants across their respective companies. The activities each participant engages in changes at every step of the process, which means that, within their respective companies, the participants need to mobilise a wide variety of skills.

To deal with this challenge, a human-centred mapping of this same process has the potential to assist with uncovering qualitative information about the roles of the different participants and analysing their contributions to the design process. I argue that it is the responsibility of the designer to perform this type of analysis, because "who does what" in the design process could significantly impact the outcome. This echoes Andrew´s observation reported in Introduction: "[E]nsuring the ship is user-friendly starts with the overall concept produced by the naval architect, but is executed over time by many dispersed members of the design team" (Andrews, 2015, p. 19). Attention to the participants´ contributions is also a central part of the ISO 9241-210 standard (ISO, 2010), and this simple mapping method helps to implement it. In the case of a collaborative process like ship design, this helps one to analyse who is participating, or not, at different steps of the process, and what is the impact of the participation or of the absence of a contribution from a participant. It also helps one to explore how to support several participants who are involved at the same step of the process.

5.1.2 Facilitating the use of human-centred, collaborative, field-driven methods

The OPAR framework introduces new methods brought in from industrial and interaction design practices, HF & E practices, and combines them with design methods from maritime engineering. In line with Visser´s cognitive framework, I refer to design activities instead of design methods in order to describe the specific design activities the participants engage in. The resulting design process built upon the OPAR framework is visualised in Figure 25 (design process level) and Figure 26 (design activities level) below. It consists of two phases:

1. Re-mapping the ship design process from a human-centred perspective to visualise the participants involved and their expected contributions to the design process.
2. Each time the design participants engage in design work and conversations related to the operation and architecture of the ship, for instance during or after a field study, the OPAR framework can be used to facilitate the design work and conversations.

The last part of the OPAR framework deals with the evaluation of a new ship architecture solution; it has not been studied in the cases I worked with.

The design activities in OPAR have the following functions:

- Facilitating participants collaboration (e.g. collaborative data analysis workshop)
- Observing and documenting end-users' experiences in their context of use (e.g. field observation, interviews)
- Analysing field observations (e.g. task analysis, layered-scenario mapping)
- Generating and evaluating concepts (e.g. paper sketching, paper mock-up, video enactment of operational scenarios combined with 3D CAD modelling)

In agreement with the HCD process described in the ISO 9241-210 standard (ISO, 2010), the observation and analysis activities help one to work within the context of use. The prototyping activities allow one to work with the generation and evaluation of solutions. To complement the ISO standard, the OPAR framework introduces four spaces (operation/architecture, as-is/preferred situation) to guide the designer´s conversations and help them navigate the process.

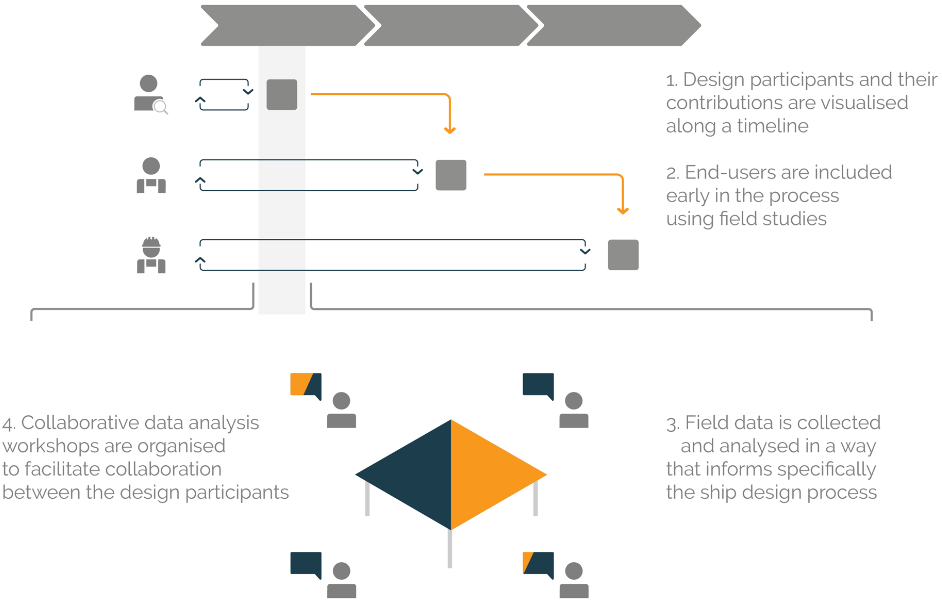

Figure 25: Design activities in the proposed process. OPAR is built to be used at any time during the process.

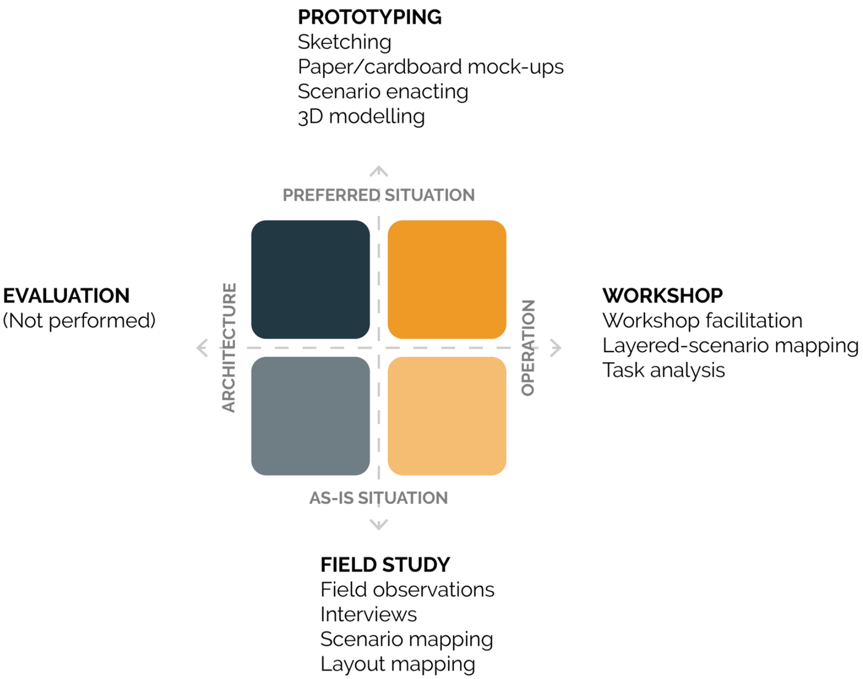

Figure 26: Specific design activities in OPAR.

All of the design activities mentioned above, except the task analysis, are part of the education of industrial and interaction designers. Research on the education of naval architects and maritime engineers to HCD principles (Abeysiriwardhane, 2017) shows that HCD methods can be used by maritime engineers, as long as there is one member of the team trained in HCD methods. The maritime engineers I worked with had no trouble understanding and applying these methods. Because field observations are subjective, observations generated by team members with no training in HCD observation methods might not be of the same quality as the rest of the team. One way to cope with this challenge is to make sure that daily debriefs with a HCD-trained designer take place during the field study. In addition, according to Lurås and Nordby´s model of design-driven field research (Lurås & Nordby, 2014), field researchers will not only benefit from engaging in observation activities, but also from experiencing the ship as a workplace.

5.1.3 Facilitating user participation

Each ONSITE field study was designed to involve the design participants as much as possible in the use of the newly introduced methods. For example, the collaborative workshop that took place after Field Study #1 involved members of the ship design company and the engine room integration company. Their participation to the workshop helped them build a shared responsibility and interest to improve the quality of the end-users' experiences. The field study findings that were analysed during the workshop were presented from the perspective of the engine room as a workplace. The workshop participants were already aware of some of the observed problems, but the focus on user experiences and their workplace shed new light on the findings. The workshop participants started discussing their own user experiences as designers and what they needed to be able to create better experiences for the engine room users. As such, a shift in focus towards end-users' experiences took place in two steps. First, the focus on the experiences of the end-users during the field study helped the designers talk about their own experiences in the design process. Second, talking about their own experiences helped the designers reflect upon what would they need to do to improve the experience of the end-users.

Lurås and Nordby (2014), based on research by Nelson and Stolterman (2003), referred to the importance of field experience in improving design judgement, which in return leads to better design decisions. Because commercial decisions are often the most important driver of in ship design processes, other factors such as design judgement need to be aligned with the actual uses of ships. Reflecting about Field Study #1 and the following work on the design of engine rooms, a participant who works with the design of engine rooms explained (Gernez, 2018):

> engine rooms don't make money and thus they are kept to a minimum, but it is still possible to make a decent engine room within a limited space if one

> knew more about how the various equipment was operated and maintained. . . . Thus, the human-centred perspective is complementary to the other perspectives, and would help the designer make better decisions.

To summarise, the human-centred reframing impacts the ship design process, which impacts in return the potential outcome of the process, and the contribution of its participants. In the engine room design example, the human-centred reframing can lead to more efficient maintenance and service interventions, as well as reduced risk of injury, failure, and operational downtime. Designers can experience first-hand the rationale and logic of human-centered requirements, and adapt their design accordingly, in a proactive way, across their respective contributions to the design process.

5.2 CONTRIBUTION 2: A FRAMEWORK FOR HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN SHIP DESIGN

The observation of end-users at work in different parts of the ship helps to build a human-centred representation of the ship operation as a combination of tasks performed at different times and places. The analysis of the ship systems used to perform these tasks helps one to connect the human-centred representation of ship operations with a technology-centred representation of the architecture of the ship. This connection can be explored in existing situations, and preferred situations can be derived from this exploration. The process can involve a multidisciplinary team that includes interaction and industrial designers, HF & E experts, and maritime engineers from different disciplines. This is the model of human-centred, collaborative, field-driven ship design that I am proposing, and this is what the OPAR framework is built to support.

5.2.1 Operation and architecture, existing and preferred situations

The dichotomy between operation and architecture addresses the lack of inclusion of end-users' experiences in current ship design processes. The OPAR framework creates a human-centred space in the design process, and gives it an equal importance to the ship systems.

The dichotomy between an existing and a preferred situation echoes Herbert Simon´s definition of design (Simon, 1996, p. 111): "Everyone designs who devises courses of action aimed at changing existing situations into preferred ones." The introduction of the human-centred perspective, which I apply to both the experiences of the end-users and the design participants, helps the design participants work with a design process in which the preferred situations are those of both end-users and design participants. This has the potential to impact the outcome of the design process, for example with a safer and more efficient ship, which in return impacts the end-users of the ship. This also has the potential to impact the design process, for example by increasing its efficiency and degree of innovation, which in return impacts the designers engaged in the process.

Using a dichotomic model relates to the problem-solution co-evolution model proposed by Maher, Poon and Tang (1996; 2003). When introducing this model, Maher and her co-authors used protocol analyses of design processes to show that the model could be used to describe design processes. When the model is used as a way to analyse a design process, as Dorst and Cross (2001) did to analyse creativity in design processes, it shows the importance of working with strategies or courses of actions that explore each part of the model and generate connections between the different parts. Maher´s original model did not include a dichotomy between existing and preferred situations because it was implicit that the exploration of problem and solution spaces would take place in both existing and preferred dimensions. I chose to make the dichotomy explicit in the OPAR framework for two main reasons. First, I wanted to highlight the role of field studies, which take place in real ships, that is, in existing situations. Second, I wanted to help maritime engineers find their bearings in the model, using the fact that ship design processes often start with the analysis of the drawings of existing ships.

5.2.2 Grounding in design theory

When introducing her cognitive framework for designing as constructing artefact representations, Visser reviewed different properties of design. In the next paragraphs, I use this review to anchor the OPAR framework by quoting full extracts from her article (Visser, 2009, pp. 193–194) and commenting on how each property relates to OPAR.

> Design is a 'satisficing' activity: rather than to optimise, that is, to calculate the optimum value, or to choose the best solution among all possible solutions, designers 'settle for the good enough' . . . . According to Akin (2001), however, . . . engineering designers adopt more objective methods in their selection among possibilities and may proceed to optimisation.

OPAR helps one use methods such as task analysis and scenario mapping, and look for solutions iteratively. Ideally, when designers judge a solution to be "good enough", they are able to consider the experience of the end-user as well as their own. Technical analyses can also be used.

> Design generally involves complex problems that are rarely decomposable into independent subproblems. Of course, designers proceed to decomposition, in order to make their problems more manageable and easier to solve.

Visser adds that there are many ways to do so, and that the activity of problem decomposing is not well understood. OPAR offers two axes along which a problem can be decomposed. The axes do not need to be strictly respected, and the conversation can be limited to only one dimension. The objective of OPAR is to connect the different dimensions, so decomposition is only used as a way to structure the data and conversations in a consistent way.

> Designers often tend to generate, at the very start of a project, a few simple objectives in order to create an initial solution kernel to which they then are sticking in what is going to become their global design solution.

Visser refers for example to Darke´s ‘primary generator’ (Darke, 1979). The reason I recommend to begin navigating OPAR with a field study is that, in my experience, the “primary generators” often come to mind while in the field. When this happens, the designer has the opportunity to discuss this idea directly with end-users and the other designers participating in the field study. This helps the designer start the design process with a strong hypothesis, which has already been partly evaluated.

> Design problems and solutions lack pre-existing, objective evaluation criteria (Bonnardel, 1991; Ullman, Dietterich, & Stauffer, 1988). As evaluative references are forms of knowledge, designers' expertise in a domain influences how they use them (D’Astous, Détienne, Visser, & Robillard, 2004).

In addition,

> In a collaborative design setting, designers may have different representations of their project, solution proposals . . . are also the object of negotiation, and the final agreement . . . often results from compromises between designers (Martin, Détienne, & Lavigne, 2006).

OPAR is built upon a co-evolutive model that encourages an iterative modification of the way design concepts are evaluated. Actually,

> Evaluation criteria and procedures themselves undergo evaluation (D’Astous et al., 2004).

OPAR combines different design activities to help designers with different experiences to understand each other and work together. New activities can be introduced into the framework, and their use is guided by what dimension(s) they enable to explore or connect. Do they enable to analyse the way an existing system is currently used? Or to prototype a different way to use this system? Or both at the same time?

5.2.3 Intended use and extended use

The way in which the design activities are combined when using the OPAR framework does not need to be predefined. In current ship design processes, only design methods that relate to the design of the architecture of a ship are used. For example, the ship design spiral model presented in Section 2.2 can be represented in OPAR by a vertical loop that iterates within the dimension of ship architecture, without going into the dimension of operation. More loose processes can be used, going back and forth between initial and preferred situations, in the dimensions of operation and architecture. By loose process, I refer, for example, to Sanders and Stappers´ (2008) "fuzzy front-end of design". In Figure 27, I visualise the process I followed with a circle that goes from the analysis of an existing situation to the design of a preferred situation, through the dimension of the ship operation, which highlights the difference with current ship design processes.

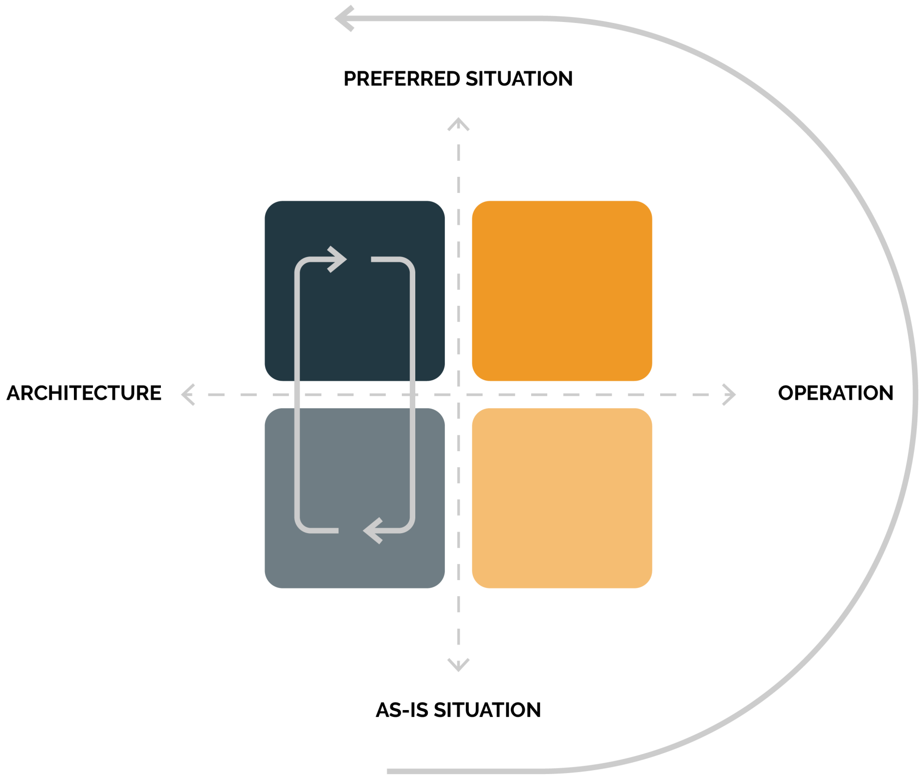

Figure 27: OPAR is built to fit with different types of design processes. Technology-centred process will navigate mainly in the architecture part; human-centred processes will navigate in both architecture and operation parts.

In terms of design theory, the flexibility of OPAR helps to implement what Visser (2009, p. 193) refers to as the opportunistic organisation of design processes:

> Designers proceed in a non-systematic, multidirectional way. . . . The basis for such organisation is designers taking into consideration the data that they have at the time: specifically, the state of their design in progress, their representation of this design, the information at their disposal, and their knowledge.

In practical terms, using OPAR helps each participant in the design process "enter the design room" with their own perspective, before combining it with the perspective of the other participants. It also enables them as a team to assess what they need to know to be able to proceed, or who else they might need to work with. It can also be used to introduce or to create new design methods that help generate connections across the framework.

5.2.4 Prototyping the operation of a ship

When working with mapping end-users' experiences with the ship systems used during ship operations, designers can navigate between existing and preferred situations. In that case, they engage with a new form of ship prototyping where a ship is prototyped in the dimension of ship operation instead of ship architecture.

Prototyping activities are fundamental in a design process because of their reflective function (Buxton, 2007). Prototyping the architecture of a ship is however dismissed by maritime engineers for its complexity and cost (Andrews, 2015). 3D CAD systems are used instead to build representations of ships. This is a problem because comparatively, physical models elicit more user feedback than CAD models (Bligård, Berlin, & Österman, 2018). One maritime engineer from the ONSITE project explained that, at the time when 3D CAD modelling programs were not available, she would build 3D models from printed out 2D plans in order to check the resulting 3D shape. She explained that now that she can design directly in 3D, she misses this way of evaluating a design.

Instead of focusing on prototyping the ship architecture, I focused on prototyping the use of a ship. For this, I used scenario mapping techniques to describe the sequence of tasks performed by the end-users of the ship. I also used a video enactment of operational scenarios combined with 3D CAD modelling. This technique is interesting because it introduces human-centred data into CAD models of ship systems. This technique resulted in the collaboration between an engineer that works with 3D modelling and a mechanic working on ships (Figure 28). The organisation of their respective work tasks would normally not require them to work together.

Other techniques can be used to make prototypes of ship operations. For example, layered scenario mapping (Lurås, 2016a) can be used to describe existing situations, but can also be used to explore different situations. Hjelseth (2016) used game engines to recreate scenarios based on field observations, so that the created scenarios could be re-enacted and modified. New scenarios can also be recreated with this method. Bødker (1996) and Buur et al. (2010) used video recording to recreate and analyse how users interact with systems. Mallman and Lundh (2014) used link analysis on general arrangement drawings as an input for engine room design. Abeysiriwardhane et al. (2015) organised workshops with cardboard mock-ups for naval architecture students to analyse ship architectures and propose new ones.

Figure 28: Prototyping session after Field Study #1: Re-enacting service interventions on an engine with a mechanic, using props to represent engine parts.

5.2.5 Stimulating creativity and innovation

The activity of generating connections between different dimensions of the design space has the potential to stimulates designers´ creativity and has the potential to yield more innovative outcomes. Dorst and Cross (2001, p. 14) used Maher´s problem-solution co-evolution model of a design process to analyse creativity in design processes. They observed that "a creative event occurs at the moment of insight at which a problem-solution pair is framed . . . . Studies of expert and outstanding designers suggest that this framing ability is crucial to high-level performance in creative design." By extension, this observation suggests that the activity of connecting operational requirements with architectural solutions (or architectural requirements with operational solutions) can stimulate a designer´s creativity.

The exploration of such connections is necessary when working with design problems such as:

- Retrofitting new systems. Because ships are designed with long lifetime, it is not uncommon to upgrade ship systems while the ship is in operation. OPAR can be used to check if new systems require a change to operational procedures. Starting from the analysis of an operation, OPAR can also be used to select a specific system that allows this operation to be performed in a better way.
- Repurposing of a ship. Also because of their long lifetime, ships can be repurposed to exploit new market opportunities. In that case, OPAR can be used at a high level to check how different operations can be used with the same ship architecture, or if the architecture needs to be modified to perform the desired new operation. Designing for uncertain and versatile operations is a dynamic field of research (e.g Agis, Pettersen, Rehn, & Ebrahimi, 2016; H. Gaspar, 2012; Pettersen, Asbjørnslett, Erikstad, & Brett, 2018).
- Designing autonomous and remote-controlled ships. This is a design case where both ship operations and architecture can be partially unknown (Rødseth & Burmeister, 2015). OPAR is specifically suited in this case because the operation of the ship is not spatially constrained to the ship, with ship control centres being designed on land. This type of design goes beyond the traditional scope of ship design. HCD is actually even more relevant in the case of automated systems from which humans are progressively being removed. In this transition phase, there needs to be an analysis of what human operators do and how they do it to derive what can be automated, and how. The more automatization is introduced, the better it needs to fit with the remaining human-operated tasks on board the ship or in shore-based control centres (Relling, Lützhöft, Ostnes, & Hildre, 2018).

To summarise, the OPAR framework is a central piece that enables to carry out a ship design process as a human-centred, collaborative, field-driven design process.

The next section focuses on what types of connection between ship end-users and ship designers are generated when using OPAR, and how they are generated.

5.3 CONTRIBUTION 3: THE CONNECTIONS GENERATED BY THE OPAR FRAMEWORK

Navigating the OPAR framework helps designers use field studies in combination with collaborative data analysis workshops and prototyping activities. In return, the use of OPAR helps to generate connections:

- between the design process steps related to the concept design of a ship, and the operation of a ship after its construction;
- between design activities carried out onboard a ship during a field study (for example, when sketching ideas generated during an observation session) and ashore (for example, during a field data analysis workshop); and
- between qualitative, user-centred data and quantitative, ship-centred data.

To analyse these connections, I use Visser´s (2006b) cognitive framework, which helps to navigate between the process steps and the activities the designers engage in at each step. I also use Visser´s cognitive view on design processes to look for what types of artefact representations are constructed when using field studies in the OPAR framework.

5.3.1 Connecting concept design with ship operation in the ship design process

The objective of the ONSITE project was to study how the use of field studies might enable one to better connect ship design and operation. In this study I consider ship operation as an object of the design process that can be discussed, analysed, prototyped, and evaluated. In current ship design processes, ship operation only comes into play after the ship is built – before that time there is no ship that can be operated. To deal with this problem, Ulstein and Brett (2012) proposed to model the ship design process based on the ship´s whole lifetime. Under this definition of the ship design process, ship operation becomes one step of the design process. However, it is still disconnected to early ship design activities, because the definition of ship operation remains technology-centred and the operation of the ship takes place chronologically a long time after the design of the ship. In this chronological, technology-centred, linear perspective, ship designers cannot perform observations on a ship that is not yet built.

The human-centred approach implemented with field studies offers an alternative. The argument is that knowledge and experience about a given situation (for instance, about the operations of a new ship to be designed) can be gathered by performing a field study on an existing one that operates in a similar way to the new ship. In that way, the study of how a ship is operated and what requirements should be worked into a new design process can take place simultaneously. The way this is modelled in the OPAR framework is by adding a whole design space dedicated to design activities focusing on the potential use of the ship, or ship operations, next to the design space dedicated to what the ship might be made of, or ship architecture. In that sense I propose a perspective on ship design that is co-evolutive, and non-linear.

5.3.2 Connecting design activities from different design traditions

In their review of the use of field studies in design processes, Kujala et al. (2003) observe that they have been limited because of the challenges to integrate them with the design process they are informing. In the OPAR framework, field studies generate a baseline that describes current ship operations and ship architecture. The baseline is analysed and challenged using the captured experiences of end-users. What systems are convenient to use when performing a specific operation? What other ways to use the system might be designed? What different systems might be designed? The ship operational and architectural spaces are explored and connections are pursued. To help this process, different design activities are used: scenario mapping, task analysis, sketching, prototyping, 3D modelling, technical computation, and analysis. Design activities are also combined through the representations of workplaces that designers build when working in the field or ashore (Figure 29).

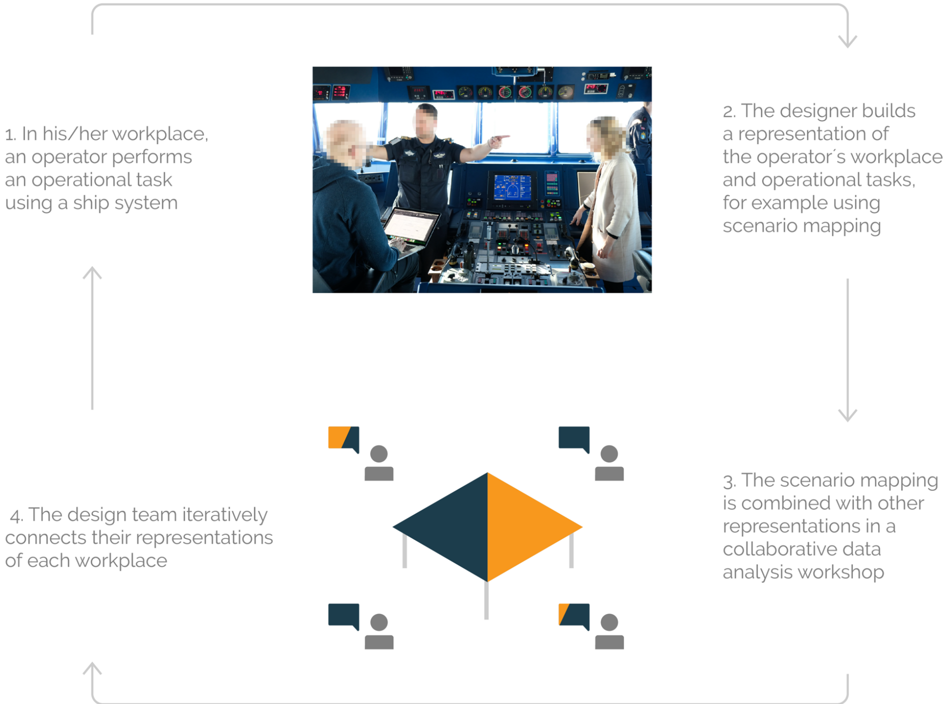

Figure 29: From the observation of a workplace to the design of a workplace.

When a designer observes the workplace of a human operator, the designer constructs a representation of this workplace and a representation of the work tasks performed by the human operator. The designer then uses these representations in his or her design of the workplace, the operational tasks, and the systems used. When several designers work together on this design process, they need to connect the different representations that they have made of this workplace. To understand one individual workplace, the designers will most likely need to deal with a larger scale and work with several workplaces.

For example, I observed that in a Platform Supply Vessel, the systems in the bridge are connected to the systems in the engine room and the engine control room when the crew engages in Dynamic Positioning operations close to the oil platform it is supplying. Design activities used in the design of one workplace will need to be combined with the design activities used in the design of the other workplaces. The human-centred model of ship operations can be used to connect these design activities. When they are connected, operational experiences captured in different locations of the ship become design material for the design of the whole ship.

5.3.3 Connecting design ashore with design at sea

When a designer works with field observations, the workplace of the observed operator becomes the designer´s workplace. This means that field studies generate a connection between design activities that take place at sea onboard ships, and ashore.

In their model of design-driven field research, Lurås and Nordby (2014) proposed that designers engaged in a field study are performing three types of design activities: data collection, reflective activities such as sketching or prototyping, and experiencing life on a ship. The OPAR framework combines these three design activities with others design activities that are carried out by the design team after the field study. In Figure 30, I have extended Lurås and Nordby's model to include additional design activities that are traditionally used by maritime engineers and traditionally performed after a field study.

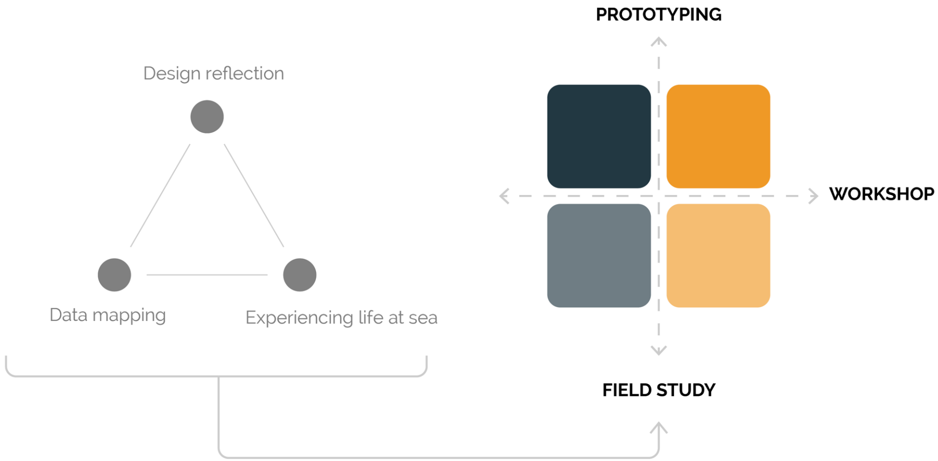

Figure 30: Lurås and Nordby´s model of design-driven field research is one example of design activity in OPAR.

The extension of Lurås and Nordby´s model contributes to expanding field-driven design activities for maritime engineers, in addition to industry and interaction designers, and make them perform such activities in tighter connection with traditional ship design activities.

5.3.4 Connecting design data

Using a combination of design activities helps to combine human-centred data with technology-centred data. For example, in Field Study #3, we used scenario mapping during the scoping workshop before the field study. During this workshop, we produced a map of ship operations by looking at how the ship systems represented on general arrangement drawings were used and in what sequence (Figure 31). To produce the map, we used Lurås´s (2016a) layered scenario mapping technique.

As another example, we used a prototyping technique in Field Study #1 that consisted of re-enacting a scenario observed during the field study. This technique allowed us to create a 3D CAD model of a ship system (an engine) next to a human avatar (Figure 32). The different colour zones represent the space required for service interventions on the engine. These space requirements include the space occupied by pieces of the engine after they have been extracted from the engine, and the space the human operator requires to perform service interventions.

Figure 31: Scenario mapping (bottom right corner) used together with a general arrangement drawing (centre) during a workshop with three maritime engineers a few hours before boarding a ship for Field Study #3.

This concept was developed during the workshop that followed Field Study #1, when it was found that service space descriptions were only formulated in terms of the space required for the tools used by a mechanic performing the service intervention, but not his or her body. As expressed by one of the workshop participants (Gernez, 2018 unpublished material):

> We consider an object that needs to be pulled out, but tend to overlook, or at least underestimate, the physical presence and movement of the persons surrounding that object in that particular operation.

The proposed concept addresses this lack by combining human-centred data (the space required by the operator to move) and technology-centred data (the engine itself).

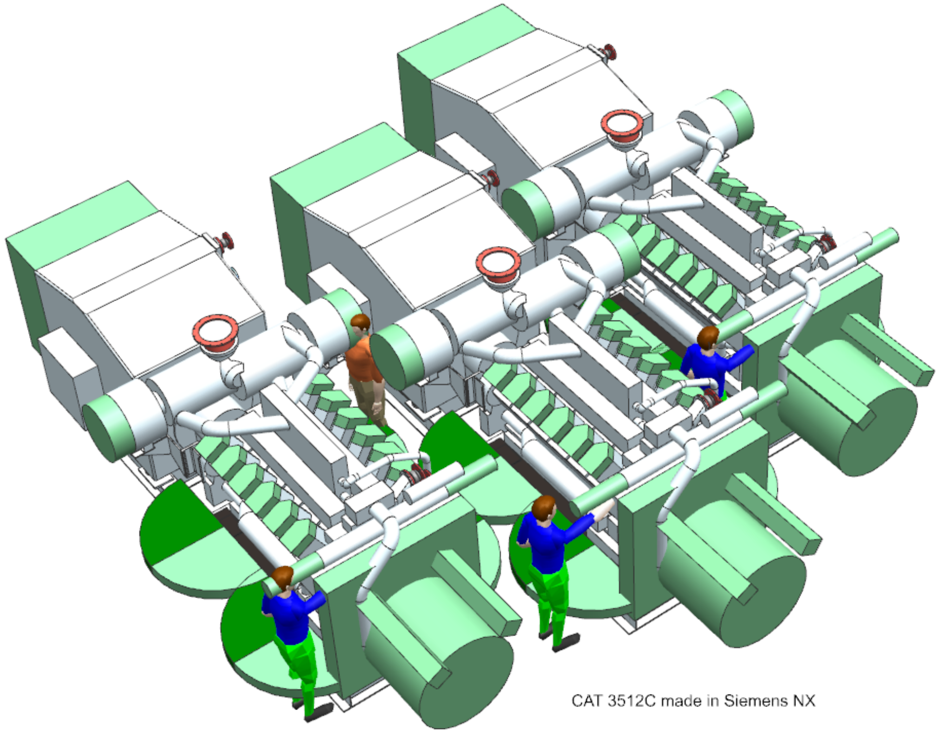

Figure 32: Concept for a 3D CAD model of an engine that includes a human avatar and space requirements for the service of the engine.

5.3.5 Connecting artefact representations

The use of OPAR helps the design team to combine data of different types: human-centred and technology-centred data, qualitative and quantitative data, field-based and "shore-based" data, and descriptive (observations, CAD models) and prescriptive (law of physics, rules, and regulation) data. This combination of different types of data leads to the construction of artefact representations that are technology-centred, human-centred, and hybrid. Examples of technology-centred representations include general arrangement drawings and CAD models. Examples of human-centred representations include descriptions of user experiences in the forms of designer observations, photos, and videos from a field study. Examples of hybrid representations include task analysis diagrams, layered scenario mapping, and the concept of a 3D CAD model that features a human avatar and operational space requirement data (Figure 33).

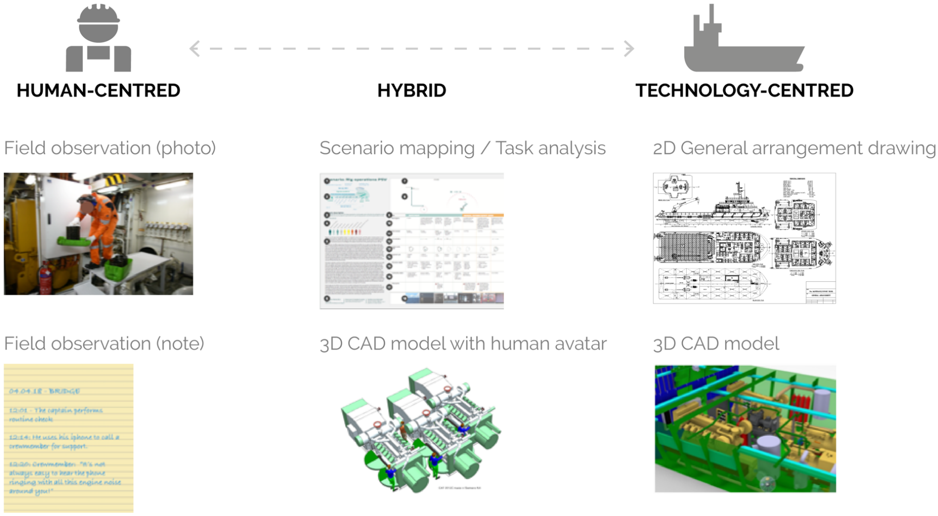

Figure 33: Human-centred, technology-centred, and hybrid ship representations.

Human-centred representations are not common in current technology-centred design processes. Neither are hybrid representations. The use of both new types of representations helps to facilitate the collaboration between designers that are used to technology-centred and human-centred representations.

The concept of a 3D CAD model that contains information about operational scenarios (Figure 32) is an example of hybrid representation. The proposed use of such a concept is versatile and works with a variety of inputs and outputs (Figure 34):

- inputs: videos from a field study, videos from a scenario enactment with a mechanic who works with service interventions on ships, interviews with ship crew or service mechanics
- outputs: interactive user manuals for ship crew and service mechanics, 2D drawings for CAD modelling engineers, or even a reconstitution of the system and its use in a virtual reality scene

As an example of hybrid representation, this concept can be used to facilitate the collaboration between different participants in the design process. Conversely, the actual design process that led to the creation of this concept was also collaborative.

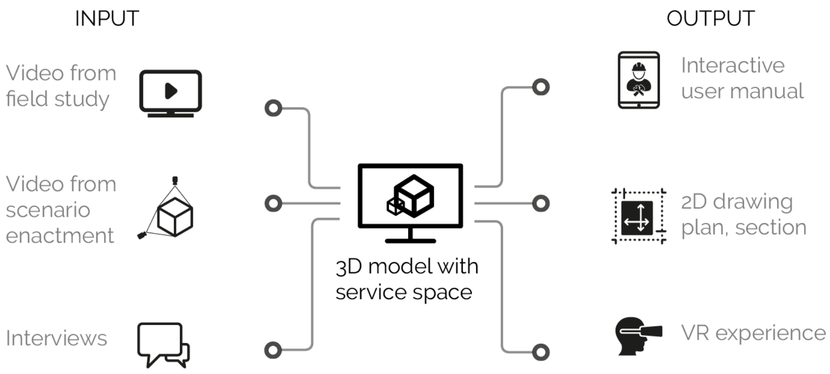

Figure 34: Inputs and outputs for a concept of a 3D model that visualises service space.

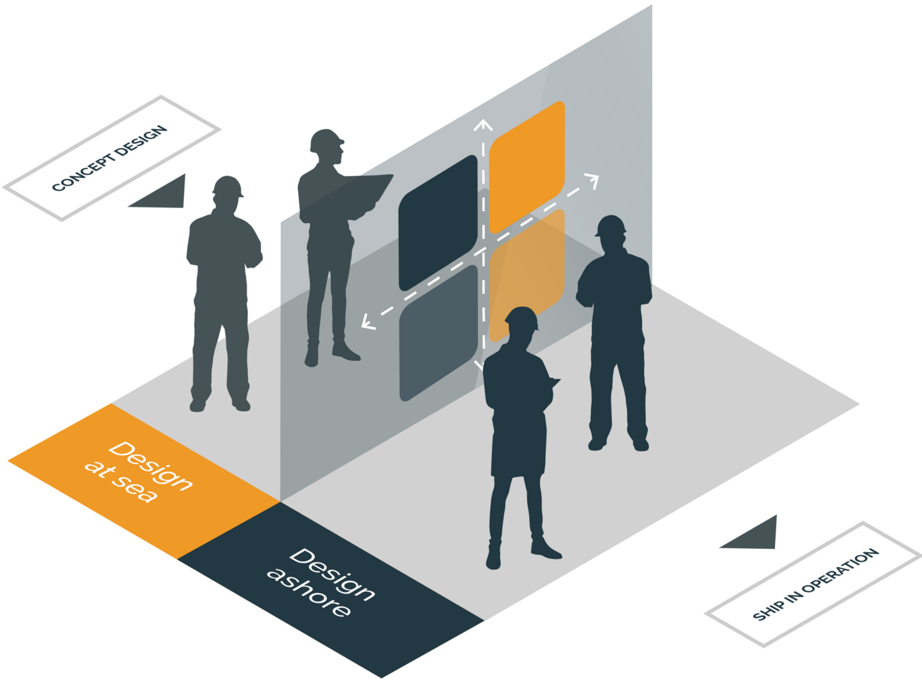

Figure 35: The connections generated when field studies are carried out inside OPAR: design process steps, design activities from different design traditions, design activities taking place at sea and ashore, human-centred and technology-centred design data and ship representations.

The different connections generated by field studies when implemented through the OPAR framework are visualised in Figure 35:

- between design process steps: concept design and ship in operation
- between design activities traditionally pertaining to industrial and interaction design, HF & E, naval architecture and maritime engineering
- between design activities taking place ashore and at sea
- between human-centred and technology-centred data and ship representations

5.4 SUMMARY OF CONTRIBUTIONS

Having introduced design methods coming from industrial and interaction design, and HF & E domains in ship design processes, I have proposed a model that reframes ship design as a co-evolutive exploration and connection of the use of the ship by its end-users and the architecture of the ship. This reframing enables to include the experiences of ship end-users as design material in the design process. It also helps facilitating the collaboration between different design participants with different domain of expertise and different design perspectives. The design framework built to support the implementation of this reframed ship design process helps specifically with carrying out field studies as part of the design process. When carried out inside this framework, field studies contribute to generate connections between at sea and ashore design activities, as well as between human-centred and technology-centred design activities, data and ship representations. The design framework emphasises the use of reflective activities such as prototyping, introducing the idea of prototyping the operation of a ship in complement to discussing its possible architecture.

In the next Chapter I discuss the quality of the research.

6 QUALITY OF THE RESEARCH

The Research Council of Norway (2000) proposes the following criteria to assess the quality of a research study:

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

In the following paragraphs I discuss the originality, solidity and relevance of my study, from the perspective of what it contributed to the ONSITE project, and what the ONSITE project contributed to its academic and industrial partners. I start with an evaluation of the human-centred model of ship design that I proposed, and I conclude with what further research avenues could be explored.

6.1 EVALUATION OF THE HUMAN-CENTRED MODEL OF SHIP DESIGN

Based on an analysis of the state of the art in relevant research domains, I outlined in Section 2.6 the following requirements for a human-centred model of ship design:

1. The process should include three disciplinary fields: maritime engineering, HF & E, interaction and industrial design;
2. The process should enable designers from these three fields to combine their respective expertise and specialist methods;
3. It should also facilitate collaboration between designers and their sub-contractors;
4. The process should involve ship end-users in a way that connects their experience to the needs of the design process;
5. The process should be based on field observation, and emphasise it as a fundamental design activity;
6. The observation of ship end-users should be structured on the work tasks of ship end-users, and include other components such as the use of systems, the organisation of work tasks and social interactions;
7. The process should also include activities to facilitate collaboration and prototyping;
8. It should include temporary representations of artefacts to facilitate their evaluation with end-users and other design participants;
9. Field observation should follow a problem-oriented ethnography with a top down approach; and

10. Field observation and analysis should be built upon the analysis of the ongoing design process it is supposed to inform.

The first eight requirements are addressed by the OPAR framework, as described in Sections 5.3 and 5.4. To support collaboration between a designer and a sub-contractor, ONSITE case #1 gives an example of how the collaborative workshop and prototyping sessions can be used (Gernez et al., 2018). In parallel with ONSITE, PON Power developed a web-based portal where simplified 3D models of engines and engine room systems could be downloaded so that designers can work with 3D models early in the design process (PON Power, 2019). I was not involved in the development of this portal, but the discussions between Ulstein and PON Power that took place during ONSITE provided a good example of a use case for the portal.

The last two requirements are addressed by the field study process developed for ONSITE, as described in Publication 3 (Gernez & Nordby, in press-b).

6.2 ORIGINALITY

In Chapter 2, I show that current ship design models focus on the design of the architecture of the ship, and not on the design of human-centred operations, nor on how to connect ship architecture and human-centred operations. From the perspective of ship design in the maritime engineering design tradition, my work brings an original contribution by introducing a human-centred design perspective to ship design, and proposing a model of ship design that captures the operational experience of ship end-users.

In the fields of HF &E, industrial and interaction design applied to the maritime domain, the work of researchers cited in Section 2.3 and Section 2.4 describe cases of introduction of HCD methods in ship design processes. My work builds upon this existing body of research by focusing on the integration of such methods into the ship design process. The introduction of the OPAR framework and the reframing of the ship design process from a human-centred perspective is a novel contribution to the fields of HF &E, industrial and interaction design applied to the maritime domain. In addition, the cases that were generated by the ONSITE project for the purpose of this research produced data that led to original material.

Finally, I have used Visser´s cognitive framework to describe, analyse and build design processes that combine activities originating from different design practices in order to create complex, collaborative design processes, particularly for ship design. Visser has used this framework to describe and analyse design processes, but not to build new, multidisciplinary design processes.

6.3 SOLIDITY

I discussed the quality of the research approach in Section 3.5. Solidity in this study also come from the reuse, extension and modification of existing models previously published.

The design-driven field research model proposed by Lurås and Nordby (2014) combined activities related to data collection, design judgement and reflection, situated cognition and experiential learning. I reused this model by including these activities in the ship design process within the OPAR framework. In that framework, design-driven field research becomes one component of a field-driven design process in which field studies are complemented with collaborative data analysis workshops and prototyping activities.

The OPAR framework itself is built upon a combination of Maher´s model of problem-solution co-evolution and its resonance with design practice theorists such as Herbert Simon and Nigel Cross, as described in Section 5.2. I extended Maher´s model by adding a dimension that frames the iterative and exploratory aspects of design processes. I extended the domain of application of the model by applying it to ship design processes in a way that introduces methods originating from different domains. In that sense, the use of the OPAR framework follows a process that is similar to the HCD process described in the ISO 9241-210 standard (ISO, 2010), although OPAR emphasises the activities that facilitate collaboration between the participants of the design process. In addition, OPAR is designed to allow for a design process that does not need to follow a predefined sequence, as opposed to the structure of the ISO standard.

There have been debates about the use of ethnography-based methods for design regarding their ability to contribute to the design process and to shape the design process itself (Petersen et al., 2011; Schmidt, 2000). In particular, the choice of theoretical framework, from which the field observation and analysis of field observations are derived, has an impact on how ethnography-based methods might contribute to design.

In the case of my research, the main reason to introduce field observations is to address the lack of inclusion of ship end-users in current ship design processes. Because this is new to ship design processes, the approach should be kept fairly simple and accessible to designers who are not familiar with these methods already. To that end, I propose that the primary content of the observations should be the study of the experiences of the end-users. To structure this study, I propose to use a cognitive work analysis approach that describes the work tasks that end-users engage with. However, the study does not need to be limited to cognitive analyses only. For instance, a description of the systems the end-users use when they perform work tasks is important. Usability observations are important and can be completed with other parameters, such as organisational and commercial considerations. Perspectives from CSCW and participatory design can be brought in to add social interactions and considerations about the responsibility of the designer.

For the generalisation and transfer of the research results to other domains outside of the maritime industry, the ONSITE project board has approved the further development of software-based solutions to support field-driven design processes based on the research produced in ONSITE. As explained in Section 1.5.5, the software development has not been my main focus, but my research has contributed nevertheless to that scope. A market analysis has been initiated to explore the need for HCD processes in sectors such as building, construction and healthcare, and to study to what degree these sectors need software to support the use of field studies in their design processes.

6.4 RELEVANCE

My research has had an impact on the practices of the participants in ONSITE, especially Ulstein. Per Olaf Brett, Vice President and Deputy Managing Director of Ulstein, explained during a project seminar that from now on they would never start a new design project without carrying out a field study. Since then Ulstein has carried out several field studies on their own, developed their own procedure for communicating internally the results of the field studies and started to train more ship designers on how to carry out field studies. DNVGL has also carried their own field studies after Field Study #2. During project seminars the three industrial partners have expressed their interest in using field studies and HCD processes to address the challenges related to working with new customers and new segments of the industry.

For the maritime industry in general, the long-term goals of ONSITE are to improve the efficiency and safety of ship operations. Considering the importance of the maritime industry in the global economy, this ambition can significantly impact society and the world economy, the atmospheric and ocean ecosystems, and the lives of many workers. Merchant ships are responsible for over 80% of transport of goods in global trade by volume (United Nations Conference on Trade and Development, 2017). Cruise ships carried an estimated 24 million passengers in 2017 (Statista, 2018a). Offshore service ships support the operations of over 1000 offshore platforms worldwide (Statista, 2018b), and over 3 billion tonnes of oil were transported by oil tanker ships in 2017 (Clarksons Research, 2018). An estimated 1.6 million seafarers worked on ships in 2017 (International Chamber of Shipping, 2018). To this figure needs to be added the number of people working with the design, construction, brokering, loading and unloading, insurance and decommissioning of ships. The turnover of the maritime industry as a whole was 1.4 trillion USD in 2004 (Stopford, 2009); as a comparison, that amount was just under the 2004 total of Italy's gross domestic product, the seventh-largest in the world (Classora, 2018).

The introduction of HCD methods into the ship design process makes HCD methods more available to maritime engineers, who traditionally have not trained in such methods. Conversely, it helps industrial and interaction designers use these methods in a design process that has traditionally been driven by maritime engineers. The field study course held at AHO and described in Publication 4 shows that design students are able to use their design skills in the context of the maritime industry.

6.5 FURTHER RESEARCH

ONSITE is one step towards the adoption of human-centred, collaborative, field-driven ship design processes. The next practical step I would like to take is to write a guide about how to practically plan, scope out and debrief field studies for organisations that are interested in repeatedly carrying out field studies. When field studies start to be used as a standard part of design processes, additional questions might be explored:

- How to flag data that has been captured during a field study, and how to follow its impact on the rest of the design process?
- How might a single field study be used at different steps of the design process?
- At what point might ship designers start to reuse insights from previous field studies without needing to perform a new field study?
- Beyond the use of software to support the use of field studies, what other technologies might improve the efficiency of field-driven design processes?
- What new design methods are required to support such technological innovations?

I would also like to further research the case of cruise ships design, because it is one case of ship design where the quality of the passenger experiences is already built into the business model of the ship, which opens for a wide application of human-centred, collaborative, field-driven methods.

7 CONCLUSION

Design failures in ship design processes lead to accidents with severe consequences. In this research, I argue that one root of this problem is a disconnect between the human-centred and the technology-centred perspectives on ship design. On the one hand, the ship can be seen and designed as a floating environment where the ship crew live and work. On the other hand, the ship can be seen and designed as an assembly of a hull, engines and other systems. The two perspectives need to be combined: ship systems need human operators to use them and operators need ship systems to execute most of their work tasks.

Ship design tends to use a technology-centred perspective, with processes and methods coming from a combination of disciplines in maritime engineering. Processes and methods coming from HF & E have the potential to bring a more human-centred understanding to ship design, yet it has been challenging for their practitioners to participate in the ship design process. Industrial and interaction design bring in methods from several other industries with a proven impact, yet with a limited application in ship design processes. As a result, maritime engineering and the technology-centred perspective still dominate ship design practices.

I propose a design process and a design framework that combine the two perspectives. The resulting ship design process emphasises the need to create a ship as a workplace where its crew can perform the operations the ship is contracted to deliver. I focus specifically on the connection between the architecture of the ship and the operation of the ship. The proposed process starts with field observations to document the tasks that human operators engage in and their experiences in using the systems that let them perform these tasks. The analysis and subsequent use of the field data is carried out in a collaborative manner in a way that combines human-centred and technology-centred design activities.

With this research, my aim is to propose a human-centred, collaborative, field-driven design process that can be used by industrial and interaction designers, maritime engineers, and HF & E experts to carry out ship design processes that are centred on the experience of ship end-users in operating the ship.

The presentation of this process follows four research questions:

1. How are users and user data integrated into current ship design processes?
2. What benefits might be created when implementing human-centred, collaborative, and field-driven methods in ship design processes?
3. How might we model human-centred, collaborative and field-driven ship design processes?

4. How might we better connect the operational experience of the ship crew with the design work of the ship design team?

7.1 HOW USERS AND USER DATA ARE INTEGRATED IN CURRENT SHIP DESIGN PROCESSES

Current ship design processes, methods, data, and artefact representations are mostly technology-centred, which limits their ability to integrate user data. For instance, I observed that end-users such as the ship crew are not included in current processes. The ways they use the ship are not analysed by ship designers. Other authors found that the way ship owners describe their need for a new ship is not modelled in ship design processes. These omissions are important, because a design process that does not cater properly to the participants who initiate the process and to those who use the outcome of the process will lead to design failures. In addition, I observed that there is no focus on facilitating collaboration between the design participants by combining their different methods, data and artefacts representations.

7.2 BENEFITS OF IMPLEMENTING HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN METHODS IN SHIP DESIGN

When the designers manage to integrate the end-users´ experiences into their design process, they get access to information about the usability of the ship systems and to what extent the designed ship systems (or ship architecture) match the end-users' needs. They also have the opportunity to benefit from the end-users' ideas to make the systems better.

To introduce these new methods, I started by reframing current ship design processes from a human-centred perspective. With a human-centred representation of a generic ship design process, it is possible to study the contributions of the different participants to the process, and to adjust the process accordingly. For example, a human-centred representation of the design process enables the design team to identify the users and user data they need in order to integrate knowledge about the operation of ships into their design process.

In the experimental design cases I carried out, I observed that the designers who participated in field studies reflected upon their own experience as designers, and how their work might impact the experiences of the end-users. When working with mapping end-users' experiences, designers can navigate between existing and preferred situations. They engage with a new form of ship prototyping that creates a prototype of the operation of a ship, instead of its architecture. Making connections between different dimensions of the design space also stimulates designers´ creativity and has the potential to yield more innovative outcomes. The concept of a human-centred 3D model of a service space, proposed during a workshop and subsequently prototyped, is one example of this kind of innovative outcome.

Finally, in addition to exposing maritime engineers with a predominantly technology-centred perspective on ship design to HCD methods, the process and framework I proposed enable them to bring in design students, HF & E specialists, and industrial and interaction designers into ship design processes.

7.3 A MODEL OF HUMAN-CENTRED, COLLABORATIVE, FIELD-DRIVEN SHIP DESIGN PROCESS

The model is built upon three parts: a model of the ship operations, a model of the ship architecture and a framework that connects the operation and architecture. The observation of different end-users at work in the ship enables the designer to build a human-centred representation of ship operations. In this model, the ship operations consist of the combination of tasks performed by ship end-users at different times and places in the ship. The ship architecture is modelled as the combination of the ship systems, with the ship as their envelope. The generation and evaluation of connections between operational requirements and architectural solutions occurs in a speculative dimension in which either the operational requirements or the architectural solutions, or both, can be modified. The OPAR framework, which thus frames the design work of human-centred, collaborative, field-driven ship design processes, is also built to support design cases such as the retrofitting of new systems on older ships, the repurposing of a ship´s mission and capability, and the design of autonomous and remote-controlled ships.

7.4 CONNECTING SHIP CREW´S OPERATIONAL EXPERIENCE WITH THE DESIGN WORK OF THE SHIP DESIGN TEAM

Connecting the design of the ship with the operation of the ship is a problem that needs to be addressed from a human-centred perspective, by looking at the respective work of ship crew and ship designers. The involvement of end-users at an early stage of the design process through a field study helps describing how ship crew use the ship, and what is their experience of using the different ship systems during the operation of the ship. The work of designers engaged in a field study consists then in assessing how the ship architecture supports the operation of the ship, and to make sure that architecture does support operation in the ship they are currently designing. To help them in this process, the OPAR framework combines design activities that focus on the analysis of operational experiences, and design activities that transfer the results of such analysis into the design of ship systems that are safe and efficient to operate. When engaging with these different activities, the design team handles data of two main types: qualitative, user-centred data and quantitative, ship-centred data. In the OPAR framework these two types of data are combined through the use of ship representations that are human-centred (such as notes and photos from field observations), technology-centred (such as technical drawings of ship systems) and hybrids (such as layered scenario mappings). When design activities and ship representations are combined, the operational experience of the crew becomes a design material where the operation of the ship co-evolves with its architecture. The combination of design activities and ship representations also helps a multidisciplinary team to work together across design disciplines, area of expertise and area of responsibility in the design process. This collaboration is a necessary component to produce ships that are safe and efficient to operate.

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9 PUBLICATIONS

Publication 1

Gernez, E., Nordby, K., Seim, Ø., Brett, P. O., & Hauge, R. (2018). Human-centered, Collaborative, Field-driven Design - A Case Study. In P. Kujala & L. Lu (Eds.), *IMDC 2018: 13th International Marine Design Conference* (Vol. 1, pp. 291–305). London, UK: CRC Press / Balkema.

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Human-centered, collaborative, field-driven design—a case study

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ABSTRACT: How can we design engine rooms that cater to the needs of their human operators? How can we do this in a design process that involves multiple companies and competences? We report on a design case where we facilitated a human-centered, collaborative design process crossing two companies. We present the methods used and the challenges experienced at each step of the process. We discuss what this process might enable for the designers, the engine room, and the ship crew. Based on our analysis, we argue that there is a need to (1) facilitate the collaboration between the companies involved, (2) collect qualitative data about the needs of the ship crews on board ships during operation, and (3) define the engine room as a human-centered working environment where the needs of human operators can be catered to. We argue that this process opens innovation venues by assisting collaborating companies in focusing on human-centered design solutions crossing the boundaries of their businesses, traditional roles and responsibilities.

1 INTRODUCTION

We present arguments for and solutions to adopting a human-centered design perspective on (1) the integration of the needs and challenges of the human operators of the ship in the ship design process, and (2) the facilitation of the human collaboration between the different companies involved in ship design processes in the maritime industry.

Across stakeholder groups involved in the ship design process such as designers (ship designer, sub-contractors, ship yard) and the end-users of the design object (ship owner, ship manager and operator, ship crew), the involved stakeholders have different levels and directions of expertise. Because of this, frameworks for understanding the separate parts of ship design can be hard to share across disciplinary gaps. This is especially important for the gap between the technical expertise of the ship designers (design) and the operational experience of the end-users (operation).

The gap between design and operation is a serious challenge since miscommunications and non-inclusive design processes can lead to suboptimal or even unsafe ship design solutions. Reviewing 29 published ship design processes, Ulstein & Brett argue that there is a need for new competences and new approaches to address this challenge (Ulstein and Brett, 2012). To address this need, we propose human-centered design methods, commonly used in industrial design, that enable the capture and exchange of the different needs of the stakeholders involved. This paper presents recent findings and results developed in the ONSITE project led by the Oslo School of Architecture and Design (AHO) together with the Ålesund branch of the Norwegian University of Science and Technology. The objectives of the project are to (1) introduce human-centered design methods to fill the gap between ship design and operation and to (2) study how this might contribute to the innovation processes of the different stakeholders involved.

The ONSITE project has generated design cases that involve a ship designer and ship builder (Ulstein group), an engine room integrator (Pon Power AS), and a Classification company (DNVGL). In this article, we present a case of engine room design that involves the ship design part of the Ulstein Group (Ulstein Design Solutions – UDS) and Pon Power. We address the following research questions:

1. How can we design engine rooms that cater to the needs of their human operators?
2. How can we do this in a design process that involves multiple companies and competences?

2 BACKGROUND

Ship design is commonly described as a decision-making process (Nowacki, 2009). Kuo observed that communication is one of the main design activities (Kuo, 2003). Ulstein & Brett argued for the need to secure "undistorted communication and equal roles in the dialog among stakeholders of the ship design process" (Ulstein and Brett, 2012). Erikstad stated that "gaining insights into the structure of the decision problem is at least as important as finding solution data" (Erikstad, 1996). It is, however, challenging to find research that proposes and reviews methods to facilitate these decision-making, communication, and insight-creating processes from a human collaboration perspective. The vast majority of the ship design research methods reviewed in the IMDC State of the Art Reports (Andrews et al., 2009, 2012; Andrews and Erikstad, 2015) represent the ship design process as a succession (or combination) of design steps, described in terms of the task that needs to be carried out before going to the next one, with the exception of Andrews´s work (Andrews, 1986). In most cases there are no mentions of which stakeholder should be involved and executing each task and what other stakeholders might be consulted. The technical parameters information to be passed on from one step to another is sometimes represented (for example, main ship dimensions) but never in terms of how the information should be exchanged. In summary, the need to approach ship design as a human-centered design activity is often mentioned, yet there is a lack of proposed methods to facilitate human collaboration.

Van Bruinessen et al. observed how ship designers deal with innovation in the ship design process. They reflected that "further research is required, but exploring this social dimension is complex: it requires research-skills related to the social sciences, but sufficient knowledge is required to understand the subject matter" (Van Bruinessen, Hopman and Smulders, 2015). DeNucci attempted to develop a tool that could help "capture a design rationale" because of its potential to assist with the documentation, validation, evaluation, and communication of design decisions between design stakeholders (DeNucci, 2012). DeNucci pointed out that this is a "human-centered" challenge and that human-centered methods were required for this task, hence limiting his ability to research this topic.

Andrews introduced a method designed to facilitate the collaboration between the naval architect and the ship owner in the preliminary design phase (Andrews, 2003, 2011). The "Requirement elucidation" method helps to synthesize user needs into an initial design brief. Andrews pointed out that at this early stage, the ship designer needs to deal with requirements set by the "requirements owner" that are often contradictory, incomplete, and change with time. In the "Accelerated Business Development" process (ABD process) developed by Ulstein & Brett, the ship designer holds a workshop with the ship owner to help list out all the requirements for a new ship and rank them in order of importance (Ulstein and Brett, 2012). Recent approaches to ship design based on multi-objective optimization all refer to the need to capture how different stakeholders perceive and value "what is a good design" (Gaspar, Hagen and Erikstad, 2016) to be able to model it into the optimization problem. These examples show the need to use methods that can assist ship designers in translating the needs of their customers into their design processes.

Using qualitative research methods such as interviews, Solesvik observed and documented how different ship design companies deal with information sharing inside the company and externally with their customers. She gives a description of the stakeholders involved, their needs for information exchange, and how the tools they use enable them to exchange information (Solesvik, 2007, 2011). Although Solesvik provides a detailed observation of human collaboration in the ship design process, she does not propose methods to facilitate this collaboration.

In terms of innovation, the facilitation of information sharing between design stakeholders is also important. Levander criticized two prominent ship design methods (the Ship design spiral and the System engineering approach) for not enabling the exploration of innovation potentials lying at the meeting points between different design steps executed by different design stakeholders (Levander, 2003). The Nautical Institute publication "Improving ship operational design through teamwork" proposed the concepts of "operational design" and "operation driven innovation," arguing for the need to include the operational experience of seafarers in the design process to drive innovation in the ship design process (The Nautical Institute, 1998). The authors pointed out that there is an inherent barrier to such innovation due to the compartmentalization of the technical and commercial departments in most ship owning companies.

The need to include operational considerations in the design process is based on the argument that the safety and efficiency of a ship depends largely on the human operators' ability to take full advantage of its capabilities. Ship accidents database analyses can back up this argument (Grech, Horberry and Smith, 2002; Kataria et al., 2015; Praetorius et al., 2015). This being the case for operational safety, it is fair to assume that operational efficiency also needs to be addressed with a human-centered perspective. This is documented, for example, in an energy management study that found that "soft measures are the lever for realizing energy savings" (Kühnbaum, 2014).

According to the ISO 9241standard definition, human-centered design "aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, usability knowledge, and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance" (International Standards Association, 2014). There have been works related to the introduction of human-centered engine room design. For instance, Mallam & Lundh (Mallam and Lundh, 2013) reviewed the current regulations for the use of human-centered design in ship design guidelines by the International Maritime Organization (IMO) related to engine room and engine control room design. They concluded that although the IMO supports this approach, it currently lacks a regulatory framework to implement it. Mallam explored methods to collect insights from engine room operators to transfer them to the ship design process (Mallam and Lundh, 2014; Mallam, Lundh and MacKinnon, 2015, 2017).

Despite this, we see only sporadic application of human-centered design methods in ship design processes. The EU project Cyclades looked into "promoting the increased impact of the human element in shipping across the design and operational lifecycle." The project developed the concept of "crew-centered design" (The Nautical Institute, 2015; van de Merwe, Kähler and Securius, 2016) for ship design processes, highlighting the need to design for, and with, the end-users of the ship. The project documented some operational requirements for different design stakeholders and end-users, but it did not investigate what specific design activities could be used to facilitate the transfer of those operational requirements into the ship design process. The Cyclades project also documented the lack of practical seafaring experience of the design stakeholders, but it did not prioritize putting the designers in direct contact with operations onboard a ship.

There has also been increased attention toward including human-centered design competence in naval architecture and maritime engineering education (Abeysiriwardhane et al., 2015, 2017). Yet there is little evidence that these competences have transcended into professional practice to any serious degree. This is not surprising considering the current and increasing complexity in ship design processes (Gaspar et al., 2012). This makes the introduction of human-centered perspectives not a matter of individual competence but, rather, a matter of building a shared understanding among all involved stakeholders in a ship design process.

In the industrial design and human–computer interaction practices, human-centered design expands the notion of usability with participatory methods that may help to design objects that cater to users' needs in an inclusive and collaborative, co-constructed manner (Bødker and Buur, 2002; Buur and Bødker, 2000). In this tradition, design processes are thought of as innovation processes that typically follow three steps: insight collection, analysis, and prototyping. These three phases are carried out with a high degree of user involvement, using human-centered design methods. We used three such methods in the present case, which are briefly presented below.

The *field study* method originates from ethnography and anthropology (Blomberg, Burrell and Guest, 2009). The goal of this method in a design process is to enable the designer to personally and physically experience the context for which he or she is designing (referred to as "context of use," (Beyer and Holtzblatt, 1997), as well as to interact with the users he or she is designing for in their living and working context. This experience is expected to enrich the designer's judgment capacity (Lurås and Nordby, 2014), which is an important foundation for the designer's ability to deliver creative and innovative solutions (Nelson and Stolterman, 2003). A *workshop* is one method that enables a group of people to work out a problem together (Sanders and Stappers, 2012). We used workshops as a part of the field study process to work out, validate, and expand the field findings in a collaborative way (Millen, 2000). Finally, *prototyping* is a central activity in human-centered design processes that enables visualizing a concept and testing it with potential users in order to criticize it and improve it in a subsequent iteration (Buxton, 2010; Rogers, Sharp and Preece, 2011; Wensveen and Matthews, 2015). Prototyping occurred throughout our whole design process in the forms of sketching, use-scenario enactment, and 3D modeling.

3 RESEARCH APPROACH

In order to study the introduction and facilitation of human-centered, collaborative, field-driven design processes, we created real cases together with the project partners where we introduced human-centered methods that were collaborative and field-driven, and we then reviewed how the cases unfolded, what they created, and what the implications for the partners' design processes might be. In doing so, the researcher assumed two roles: a participant in the case and an observant of how the case unfolded. This type of approach is referred to as Participatory Action Research (Whyte, 1991).

The present case was initiated by Pon Power to better understand the experience of their end-users working in engine rooms: *How can we design for better experiences of ship engine rooms?* The case then followed a standard, open-ended, exploratory innovation process in which the exact content and outcome of each step was not known in advance: insights collection, insights analysis, and prototyping. The design methods used to implement this process were a field study, a workshop, and prototyping through the modeling of operational use-scenarios in a 3D CAD model. The case is summarized in Table 1 and presented step by step in Section 4. Throughout the case, a variety of data material was gathered, as presented in Table 2.

We reviewed the case outcomes in light of the research questions put forward in this article. We analyzed (1) how the design methods we used in the case captured the information describing the needs of the engine room human operators and (2) how this information was shared and dealt with in the design process across the different stakeholders involved. We based this analysis on the "actor centric mapping technique" developed through the ONSITE project (documented in an upcoming guide, (Gernez, 2018). It visualizes a process along a timeline, showing the stakeholders involved in the design process and information related to their contributions to the design process, for example, their roles or what activities they carry out, throughout the different steps of the design process.

Finally, we discuss the potential impact of this work on the engine room design process and its outcomes for the stakeholders involved. The discussion is based on the informal interviews of project participants throughout the project, as well as two half-day seminars with all the project partners. During the seminars, the status of the case was presented and used to collect the partners' feedback on what is important for them in the produced research and what should be prioritized further.

Table 1. Case summary.

	Field study	Workshop	Modeling of use-scenarios
Insight collection with	Ship crew, during ship operations, onboard ship	Engine room integrator, ship designer	Engine room integrator, engine mechanic, yard construction supervisor
Insight analysis with	Engine room integrator	Engine room integrator, ship designer	Engine room integrator
Prototyping steps	Early concept	Co-designed, refined concept	Prototype version 1.0

Table 2. Case data.

Data material category	Description
Visual maps	Visual notes from meetings and interviews (2D, A4 pages)
Hand-drawn concept sketches	Documentation of concept process in 2D, on paper
Rendered concept sketches	Produced by industrial design student
3D model prototypes	Produced by Pon Power
Meeting notes	From internal meetings at AHO and with Pon Power and Ulstein
Project logs	Time-based documentation of project progress
Field notes	Observation and reflection notes from the field study, workshop, and prototyping session
Field media	Photo, video, and audio material collected during the field study, workshop, and prototyping session
Presentation material	Presentations in Power Point format used to facilitate discussions with project participants during the field study, workshop, and seminar
Seminar interviews	Notes from seminar
Informal interviews	Notes from discussions with project partners

4 DESIGN CASE

4.1 *Field study*

The field study took place in the North Sea in December 2016 onboard a Platform Supply Vessel designed by Ulstein and built in China, with engine room systems provided by Caterpillar and Pon Power. It was carried out by one field researcher from AHO. The researcher was on board for 5 days. The objective of the field study was to collect first-hand data about the experiences of users of Pon Power engine rooms. This fed directly into the innovation process that drove the case: "*How can we design for better experiences of ship engine rooms?*"

From the start, the field study was designed to be human-centered by focusing on crew activities and by structuring field information about ship systems from the perspective of the use of the systems by the crew. The field study focused on: (1) the different tasks the crew members performed during the different phases of the ship operation, (2) the systems the crew members used to perform these tasks, and (3) the experience of the crew when using these systems while performing these tasks.

The field study was composed of different activities that needed to be performed in sequence to be effective (the produced results are useful for the design process informed by the field study) and efficient (a minimum of resources is used to produce these results). The activities are presented in Table 3.

The background and planning began with building an initial list of tasks and systems that we expected to be able to observe on board the ship and how we might go about the observations. To do this, we interviewed a researcher expert in field observations in engine rooms. Using the interview, we built an observation guide that indicated who to talk to and what location on the ship offered the best context for the conversation. The guide also indicated the best moments to carry out specific observations in regard to the ship's different operation phases. This was important because the field study needed to take place on top of current ship operations without disturbing the operations and respecting the recovery and recreational time of the crew when they were not on a shift. Then, we interviewed Pon Power employees that work with engine room modeling, system integration, and service. We visited their production site. This enabled us to understand their design process and adapt the field study to connect to it. Finally, we produced a detailed field study plan that was communicated to and approved by Pon Power, the company owning and managing the ship we studied, and the captain and crew. This helped create a shared understanding among all the stakeholders involved and secure their full participation.

Table 3. Field study activities.

Activity	Role
Scoping	Specifies what type of information needs to be collected
Background and planning	Specifies how to collect this information
Execution	Collects field information
Analysis	Structures field information, derives conclusions
Presentation	Communicates main findings and conclusions

Table 4. Field study process.

Activity	Outcome	Method
Field study scoping	Common understanding of field study goals	Face-to-face meeting and phone and email conversations
Background research	Observation guide: what to observe and how to observe it Map of Pon Power's design process	Interview with engine room observation expert; Interview and production site visit
Field study planning	Communication of field study goal, scope, and methods to all stakeholders	Plan drafted, then circulated to and approved by stakeholders
Field study execution	Pictures, videos, audio capture, hand-written notes, sketches, typed-up observations, and reflections	1 field study researcher followed the field study plan and adapted it to the ship operations taking place during the study
Field study results analysis	Selection of annotated photos and videos. List of observations and reflections	2 researchers reviewed, sorted, structured, and annotated the field data
Presentation to and analysis of results with Pon Power	Summary of observations in a Power Point document; draft plan for next phase	Summary document was presented and discussed during a face-to-face meeting

The observations collected during the field study consisted of: photos, videos, audio capture of interviews, and hand-written notes. The most significant observations took place at the very end of the field study when a maintenance intervention (changing the oil filters on one engine) was carried out on the way back from an oil platform to the logistics base on land. When back to shore, the data was reviewed by two researchers from AHO. The data was sorted and structured into observations and reflections related to the field study goal and objectives. We prepared a Power Point presentation summarizing the field study experience, illustrated with relevant media (photos and videos). We presented this summary to Pon Power and analyzed the findings together. The goal was to agree on what identified problem areas should be targeted and how to reframe them as innovation opportunities. The process is summarized in Table 4.

4.1.1 *Findings*

Field observations (Figures 1–4) showed that the crew was exposed to safety-critical risks (head injuries, slips and falls, burns) and that there were ergonomic issues (lack of body support and non-ergonomic body positions) as well as efficiency issues (tools and spares spread in different places, no protection nor recovery measures for important tools). We also observed that the crew made their own ad-hoc tools and their own solutions for routine cleaning and routine checks, which is evidence of a system design that does not entirely satisfy the needs of its users. The problem areas were summarized as:

Figure 1. Absence of working surface on the engine. The mechanic needs to place the tools and spares directly on the engine.

Figure 2. Service tools are stored in small boxes inside a larger box, making it inconvenient and time consuming for the operator to find the required tool. The lid of the tool box fell over the mechanic´s head during the operation.

Figure 3. Risk of head injury, trip, and fall, as well as oil spill. While carrying used oil filters in a receptacle full of oil, the mechanic needs to climb down stair steps while bending his back and knees to avoid hitting a beam with his head.

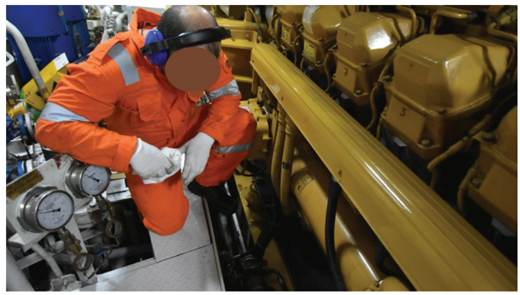

Figure 4. Constrained space around the engine, lack of body support and non-ergonomic body position. The mechanic is resting his elbow on pressure and temperature gauges that are not designed for carrying weight. Both his feet are only halfway resting on the flooring.

> "The engine as a working place": the engine needs to be seen as the central element of a working place where human operators need to carry out work tasks every day.
>
> "Engine integration in the engine room": the engine integration in the whole engine room needs to enable the human operators to carry out their work tasks in the most safe and efficient way.

The problems were reframed in terms of innovation opportunity: by delivering safe and efficient working spaces, Pon Power can differentiate itself from its competitors. Because the ship designer designs the whole engine room, we agreed that the next step needed to be an innovation workshop with the ship designers from Ulstein Design Solutions.

In summary, the field study enabled Pon Power to articulate their challenges and innovation opportunities in terms of human-centered engine rooms and to advocate for a human-centered approach to the collaborative design process of engine rooms.

4.2 *Innovation workshop*

The objectives of the workshop were to (1) identify use-cases or design problems that repeatedly take place in engine room design activities, (2) identify entry points or ways into these problems, and (3) sketch opportunities for innovations.

Before the workshop, we recruited the personnel that had the mandate and competence to explore problems and implement solutions in their design process. From Pon Power, we recruited the technical director and an engineer in charge of modeling individual systems and their integration in engine rooms. Both worked all along the product chain, with sales and service teams on each end. From Ulstein Design Solutions, we recruited two engineers involved at the concept design stage, both specializing in machinery integration, as well as an engineer working with detailed design downstream in the design process. Still before the workshop, we briefed the workshop participants using a 5-minute video documenting a service intervention from the field study that showed several safety and efficiency issues. During phone interviews with each participant, we asked what they thought about the service intervention, what problems they saw, what might be the root of the problem, and what possible solutions they could think of. This enabled starting the workshop with an already established, common understanding of the problem at hand and a list of questions that could be addressed collectively:

1. How much do we know about engine room use, for example, like service scenarios? How can we find information about it?
2. How can we visualize such scenarios in 2D drawings and 3D models so that they can be used as input to the design process?
3. How can we manage the collaboration among the engine room integrator, the ship designer, and the yard to make sure the engine room is built according to the final design drawings and models?

Before the workshop, we also prepared visual concepts to synthesize the ideas we had discussed and developed so far with all the stakeholders. The visuals were also produced to support the workshop conversations by referring to specific ideas and to trigger further ideation processes by criticizing and improving the ideas. We sketched a concept of a human-centered engine room (Fig. 5) that included specific space requirements, such as space for circulating around the engine, flat working spaces, tool and spares storage, and space to manipulate the tools and spares used to service the engine. The space requirements were visualized as volumes on a

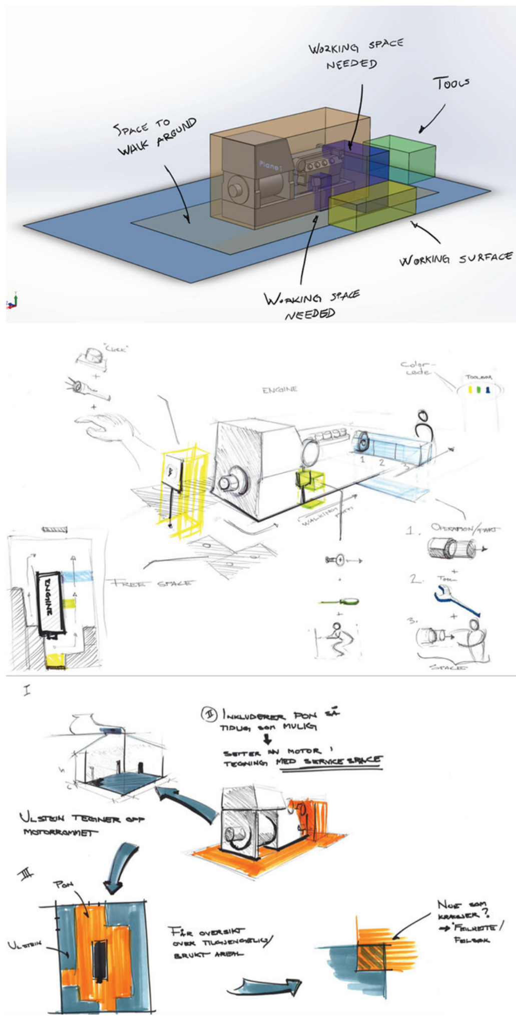

Figure 5. Concept sketches for a human-centered engine room. Top: concept for a 3D model of an engine that visualizes the space required for access around the engine, working surfaces, and tool storage as volumes of different colors. Middle: concepts for information that should be captured in the space requirements: body of the operator, tools, engine parts. Bottom: Color codes signalizing the design responsibility of different design stakeholders in the engine room.

3D model with a color code indicating which stakeholder had the responsibility of the design in each area and which areas should be kept free of anything that might come in the way of the human operator.

The workshop itself took one day, including breaks, lunch, and transportation time. Two facilitators ran it, one facilitating the discussions and the other taking notes and visualizing ideas and concepts. The participants worked with the list of questions presented above, sharing their ideas on Post-its on the wall. Toward the second half of the workshop, the findings were summarized by one facilitator, and a plan was laid down that detailed a new concept co-created by the participants and how they might collaborate to develop it further. The workshop was documented with photos and videos, and a summary was shared with all the participants after the workshop. The process is summarized in Table 5.

4.2.1 *Findings*

The participants commonly agreed on the need to design engine rooms that enable service operations in good conditions. They collaboratively defined who the design stakeholders were that produced the information that informed this design process, as well as the design stakeholders that used this information in their design process. The groups of information producers and users were found to be overlapping: engine room integrator, concept designer, arrangement engineer, yard engineer, engine room crew, and machinery specialist working on land for a ship owner, as well as Class or verification authority and third-party service provider. Following, the workshop participants collaboratively agreed on the end-user needs: ergonomic body position for working, good access to engine parts, room around the engine for operation-maintenance and repairs, proximity to storage of spares, and service-friendly design while the ship is in operation. They agreed on examples of scenarios that might be used to qualify and quantify the required space: engine maintenance (pull out and exchange cylinders, change oil filters, tap and drain oil), operation (cleaning engine, performing temperature and other readings), and repair (dismantling, spare transport and lift, spare assembly). Finally, the workshop participants agreed that the main motivation was to improve the safety of the users, engine systems, and tools used to perform maintenance and repairs.

The participants continued exploring their own design processes and the challenges created when their respective design processes intersect. They mentioned that misunderstandings and wrong interpretations of design documents are common. This is a problem not only for the end-user but also for any stakeholder that produces the design of a ship part that ends up being built differently, as it impacts the quality of the final product and the image and reputation of the design stakeholder. They explained that the main reason for misunderstandings is that the information about space requirements in engine rooms is dispersed in different documents, handled by different design stakeholders, and presented in formats that are not able to carry the correct information. For example, the engine integrator produces user manuals for the engine systems in text formats, from which the ship designers select information they need to produce their own user manuals that are delivered to the yard. The engine integrator also produces visual descriptions in 2D drawings, but they typically only indicate the space taken by engine parts on the drawings and not the space required for the body of the human operator. When the ship designer or the yard turn the 2D drawing into a 3D model, there can again be information loss or misinterpretation.

The initial concept of the human-centered engine room modeled in 3D that was prepared before the workshop was expanded by the workshop participants. They added several layers of information to the model, each one displaying the space requirements for one use-scenario. They

Table 5. Innovation workshop process.

Activity	Outcome	Method
Mobilize workshop participants	List of confirmed workshop participants	Phone calls
Edit field data video	5 min video showing one service intervention on board	Software to edit several video clips and blur the face of the mechanic performing the service intervention
Discuss video with participants	Common understanding of the problem	Phone interview with each participant
Prepare inspiration visuals	Handmade and digital sketches	Industrial design student sketching
Run workshop	Co-created concept and implementation plan	2 facilitators. 3 main questions. Post-its on wall.
Share workshop documentation	Summary of workshop insights	Photo and video documentation

proposed ways to quantify space requirements for each scenario using videos from field studies, videos made by mechanics onboard the ship or on land in the workshop where the engines were being assembled, or on interviews with mechanics. They proposed using the model to check if other systems around the engine collided with the service space, enabling a test of the engine room design before it is built. The concept and its collaborative design process are visualized in Figures 6 and 7.

In summary, there were two main outcomes of the workshop. First, the participants managed to create a common understanding of the engine room design requirements when built from the perspective of the end-users and the design stakeholders in their respective contexts of use. Second, the participants managed to sketch a collaborative design process and a collaborative format supporting this process that were adapted to their own respective design processes.

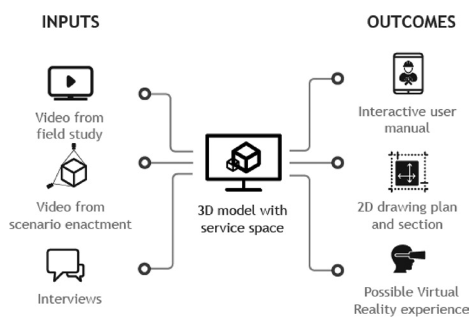

Figure 6. Concept of a 3D model of service space. The model can be built using different types of inputs, and can be used to generate different outcomes.

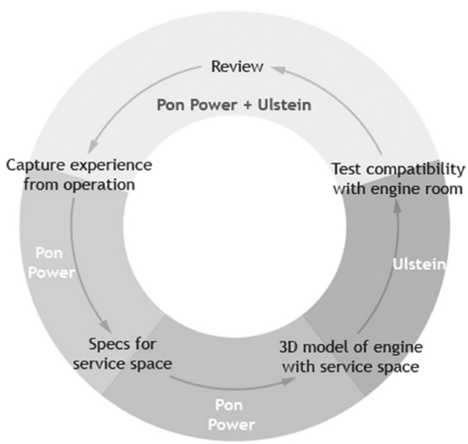

Figure 7. Collaborative process to produce a 3D model of design space, between the engine room integrator (Pon Power) and the ship designer (Ulstein). The process is designed to be iterative, hence its circular shape.

4.3 *Prototyping: Modeling of use-scenarios*

The objective of this phase was to start prototyping the concept developed through the field study and the innovation workshop. A 3D model with a human avatar next to an engine was made by Pon Power using Teamcenter NX software. We organized a session at Pon Power's office where different engine interventions were filmed. A service mechanic showed how the intervention is done, what tools are used, and what steps are usually challenging to perform. Two sets of color tapes were laid on the floor around the engine at 0.5 m and 1 m to the engine center line to give distance indications in the video recording. We found and built props on the spot to approximately reproduce the sizes and shapes of different engine parts and servicing tools. Three examples are shown in Figures 8–10.

Figure 8. Space requirement capture for use-scenario: oil filter change. Note the room taken by the body of the mechanic when enacting the movement of pulling a filter out of the engine.

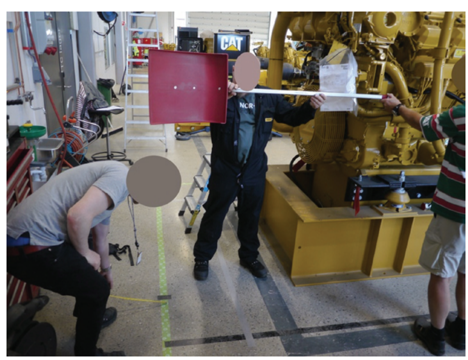

Figure 9. Space requirement capture for use-scenario: crankshaft removal. The crankshaft need to be pulled out entirely, requiring a lot of space.

The filming session took approximately two hours, with a total of five scenarios filmed. The session involved a project engineer, mechanic, and yard supervisor. It gave them the opportunity to share their experience with engine modeling, service intervention, and construction challenges.

The space requirements were then integrated into the 3D model. Each component of the engine that can be removed during a service intervention was movable, and the space needed by the human operator to perform the intervention was displayed in the model, both in 2D and 3D, using volumes. An early prototype is shown in Figure 11.

Figure 10. Space requirement capture for use-scenario: genset adjustment. The mechanic demonstrates the use of the tool required for this operation: a key with a long lever arm. To manipulate the key, the mechanic is standing one meter from engine.

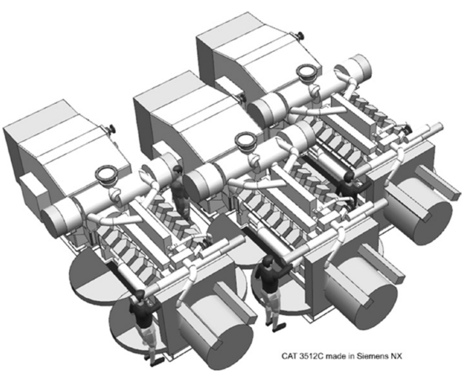

Figure 11. Early prototype of the 3D service space digital model with a human avatar and a color code: grey and light grey areas need to be kept clear of any other system to guarantee for service space. In this scenario, the avatar is in the position for removing an oil filter. Having 3 engines enables displaying this information on each side of the engine, including between two engines located side by side, as is often the case in compact engine rooms.

5 ANALYSIS

5.1 *Design process*

To analyze the design process followed in the case, we asked:

– What participants were involved?
– How did they work together?
– How are the needs of human operators captured and transferred into the design process across the different design stakeholders involved?
– How different is that compared to common practice?

We started the analysis by looking at how a ship design process would take place without any specific human-centered design intervention. We mapped such a process using the “actor centric mapping technique” based on data collected previously (Gernez, Nordby and Sevaldson, 2014). The result is shown in Figure 12.

We made two main observations from this mapping. First, each stakeholder interacts with at least two other stakeholders at every step of the process. In addition, the role of each stakeholder changes at almost each design step, which means that different teams with different competences and responsibilities need to be involved at different steps.

This means that there are also complex interactions inside each stakeholder company. Second, the end-users, such as the engine room users, are not involved in the design process. This means that the stakeholders designing and constructing systems for them do not know how usable the systems are or whether, how, or to what extent they address the users’ needs. They do not have the opportunity to benefit from the ideas the end-users might have to make the systems better.

These observations showed that there are two important needs to address:

1. The interactions between the engine integrator, ship designer, and yard on the one side, and the end-users on the other side are not currently part of the design process. They need to be added to allow the design process to benefit from operational feedback.
2. Because the design process is built upon numerous and complex interactions between stakeholders, there is a need to facilitate these interactions from both the information exchange and human perspectives.

In Figure 13 and Table 6, we map and analyze how the design process we contributed to might have addressed these two needs.

Table 6 and Figure 13 show that both the inclusion of end-users and the facilitation of the collaboration of design stakeholders were addressed in

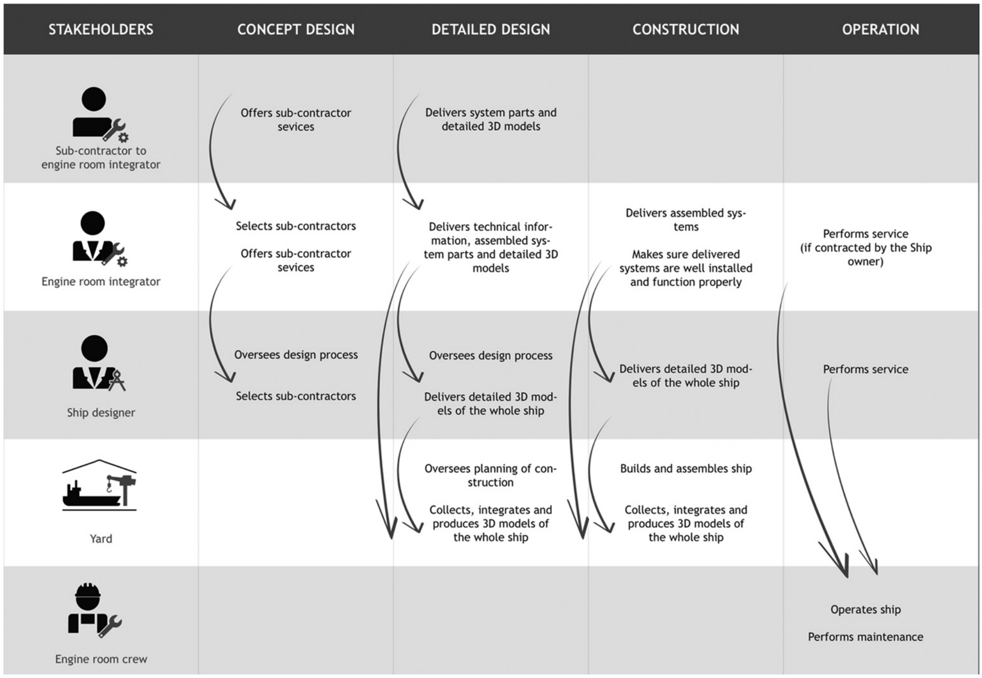

Figure 12. Actor centric mapping of a generic ship design process at a high level.

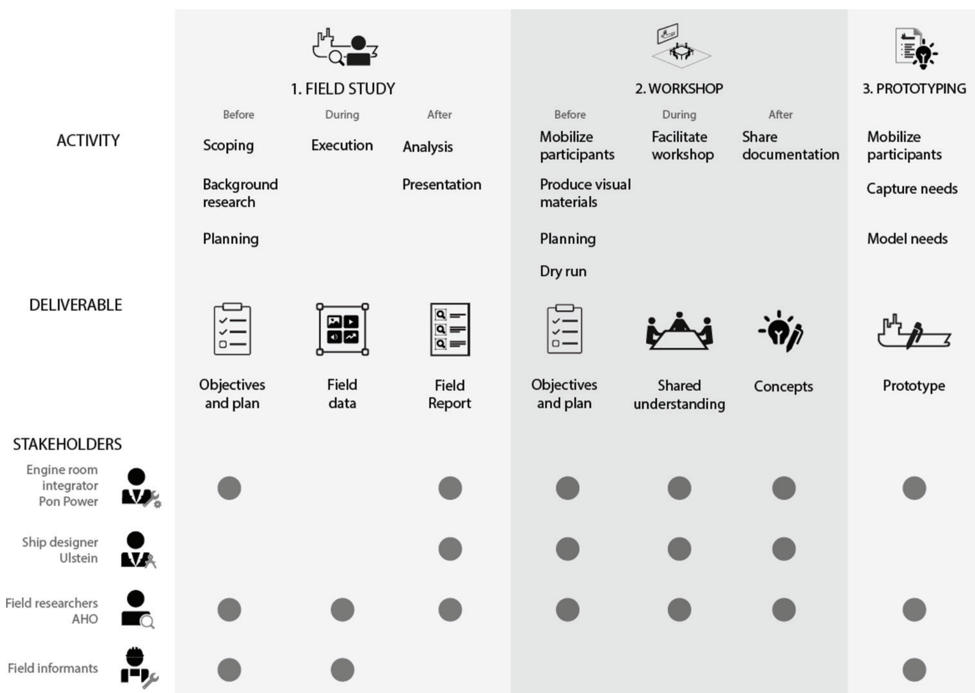

Figure 13. Mapping of the design process used in the presented case.

Table 6. Analysis of addressed needs.

	Field study	Workshop	Follow-up
Addressing the need for "involving end-users into the design process"	Observations of end-users in their working environment were captured, analyzed, synthesized, reframed, and shared back with the engine room integrator.	(1) a video of use-scenario as observed on board was shown to and discussed with ship designers before the workshop. (2) the workshop lead to a concept for how human operations can be captured during field studies and then modeled in engine room models, early in the design process.	(1) a service mechanic showed to a modelling engineer what is important to design for when designing for service scenarios. (2) the modeling engineer created a 3D model with a human avatar that simulates these service scenarios.
Importance	The engine room integrator now possesses data documenting engine room use experiences and has alternatives for ways to intervene.	The field data is shared with and worked upon with ship designers: operation data is one step closer to the early design phase.	Another end-user was brought into the design process: a service mechanic working with service intervention.
Addressing the need for "facilitation of design stakeholders collaboration"	Engine room integrators expressed the need to meet ship designers to work out how to improve the user experience of the engine room.	Engine room integrators met with ship designers and worked on co-constructing descriptions, definitions, needs, requirements and innovation opportunities.	A service mechanic, modelling engineer and yard construction supervisor, representing 3 different departments, met and exchanged perspectives.
Importance	The field data was used as evidence for the importance to have this meeting.	Together, these two design stakeholders from two different companies found a way forward, that also has potential to improve their own processes internally: time saving, increased knowledge sharing	The three design stakeholders from Pon Power learned how to arrange such a knowledge sharing session. They now have a digital format to capture and share the results of such a session.

our process. They also show that the three phases of the project are important to follow. The field study needed to take place to create the conditions for a productive workshop. Conversely, the workshop enabled to transform field study insights into an innovation concept. The prototyping session following the workshop enabled to test the concept and produce a first iteration of it.

5.2 *Impact*

Mallam & Lundh (Mallam and Lundh, 2013) and others (The Nautical Institute, 1998, 2015) showed the existence of human-centered requirements for the safe and efficient use of engine rooms. These requirements are produced by design stakeholders such as Class, HF experts, and experienced seagoing crews that are not practically designing the engine room. In our case, the design stakeholders that were practically designing the engine room defined these requirements.

The concept of human-centered engine rooms developed in this case has the potential to enable more efficient maintenance and service interventions for the end-users of the engine rooms, which reduces the risks for injury, system failure, and operational downtime.

For the design stakeholders involved, the use of human-centered design methods has the potential to improve the detection of design flaws and, consequently, to reduce the risk of additional design iterations to correct these flaws. Without these methods, it is challenging to consider parts of the ship from a dynamic perspective. We are, however, aware that the commercial perspective rules the main dimensions of a ship, and spaces and areas that are not directly involved with the main commercial functions of the ship are kept at a minimum.

5.3 *Complementarity with ship design methods*

The approach we propose is designed to be complementary to the way ship design processes are currently carried out. In the case described in this article, the approach is used on the design of engine rooms, but the approach is applicable the design of other ship systems as well. We visualize in Figure 14 how the human-centered design methods we have used can be placed in a simplified design process that connects the human-centered design components of the design process (what we refer to "Ship operations") with the technology-centered components (what we refer to "Ship architecture"). Similarly to starting a design process by looking at existing ships, we recommend to start the design process by a field study on a similar ship to map the working and living conditions of the end-users of the ship, as well as how they are performing ship operations currently. Using these field insights, we then recommend to analyze how the existing systems on board the ship enable its human operators to use the ship, and identify design problems that might impact the safety and efficiency of ship operations. From this analysis, we recommend to sketch what architectural solutions might enable the human operators perform their work in better conditions.

5.4 *Limitations*

We presented only one case in this paper, which limits the generalization of the impact of human-centered design methods. We have applied the same approach to two other cases in the ONSITE project. Referring to one of these cases, Ulstein Vice President Per Olaf Brett commented in a project seminar: "From now on, we will never do a new ship design project without using the field study methodology."

As illustrated in Figure 13, there is a high dependency on the design researcher to facilitate the use of human-centered design methods. The design researcher intervenes at each step of the process, as a field researcher in the field study, a facilitator in the workshop, and a contributor to the concept ideation and development throughout the whole process. In other ONSITE cases, the project partners have carried out field studies and run workshops on their own.

Looking at the cost of our approach, the field study took approximately 100 hours for the field researchers from initiation to conclusion. The innovation workshop took approximately 50 hours for the field researchers from initiation to conclusion. These costs need to be transferred to the design process costs. Considering their potential impact on the design process and the ship operations, these costs are negligible in comparison to, for example, the cost of one design iteration or one day of ship operational downtime. As expressed by Per Olaf Brett during a project seminar in November 2017: "Cost [of field studies] is not an issue. (…) Field studies can be very valuable for the downstream design process."

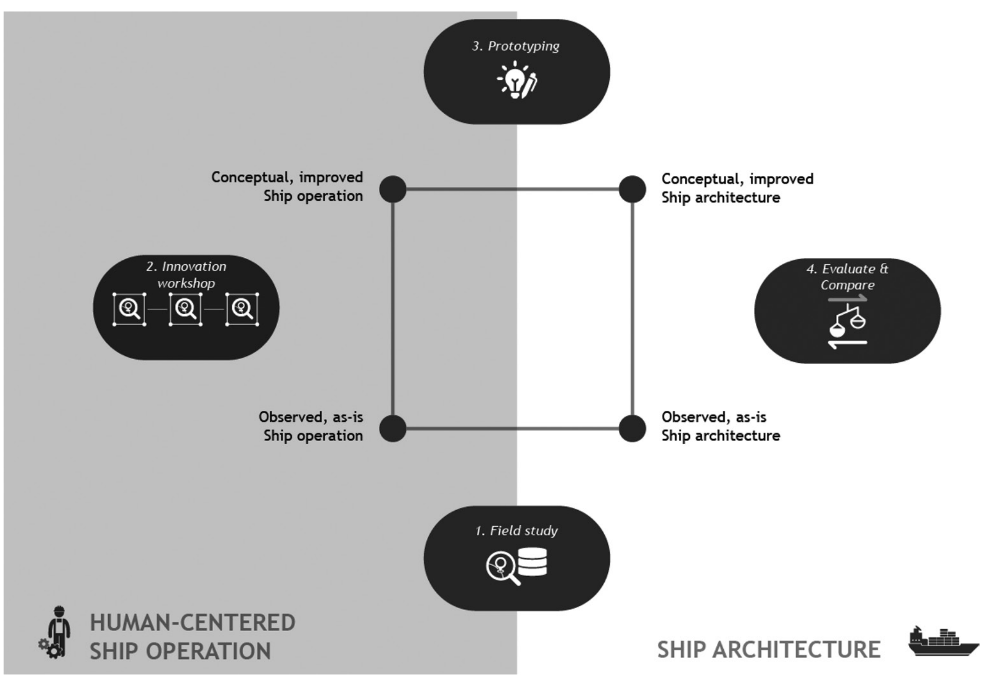

Figure 14. A design framework for human-centered, collaborative, field-driven design processes.

In terms of proximity to the end-users and their working environments, there are no alternatives to performing a field study. However, once a field study is performed, its results can be used over several design projects if there is a similarity in scope. The experience of the designer during the field study is also relatively transparent to the type of ship.

6 CONCLUSION

Using human-centered design methods in the design of engine rooms brings stakeholders together on common, shared issues and responsibilities that they can solve together to improve their own and collaborative design processes and, as a result, improve the quality of the outcomes for end-users. The requirements for implementing this approach are to (1) facilitate the collaboration between the companies involved, (2) collect qualitative data about the needs of the ship crew on board ships during operation, and (3) define the engine room as a working environment where human needs can be catered to.

These requirements are similar to human-centered design projects in other industries, for instance the Oil & Gas industry, where the involvement of end-users is a more common practice. Further research is needed to analyze how the uptake of human-centered design methods can be better facilitated, with regards to training, multidisciplinary collaboration, and the combination of user-centric, qualitative data with existing Computer Aided Design systems and ship design processes.

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Connecting Ship Operation and Architecture in Ship Design Processes

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It is challenging to deal with the operation of ships by crew members in ship design processes. This is important because the efficiency and safety of ship operations ultimately depends on the ability of human operators to use the technological systems designed for them, no matter how well the technology might perform. The challenge is that there are limited ship design processes combining coherent coevolution of ship architecture and ship operation. I propose a framework that helps ship designers connect the operation of ships by human operators with the design of ships and ship systems.

Keywords: design (general); operation (general); safety

1. Introduction

Analysis of the actual uses of ship systems by human operators can inform the design of ships and ship systems with the aim of making them safe and efficient to use. However, this analysis is challenging because human-centered design (HCD) methods are not common in ship design practice and research (Lützhöft 2004; Lundh et al. 2011; Lurås & Mainsah 2013; Costa & Lützhöft 2014; Abeysiriwardhane et al. 2015). This research explores how HCD methods can be introduced to the ship design process. In this article, I present a set of human-centered methods structured into a framework that connects the operation of ships by human operators with the design of ships and ship systems.

Rothblum (2000) states that designers need to understand the tasks of the human operators during ship operations and use this understanding to create designs that are compatible with all the systems the ship users interact with. Research on ship accident statistics supports the importance of this claim and shows that most accidents are connected to errors by human operators in their use of and interaction with ship systems (Kataria et al. 2015; Praetorius et al. 2015). There are good reasons to suppose that, similar to safety, the efficiency of ship operations is also closely connected to how ship systems enable the human operators to perform their tasks efficiently.

From a human-centered perspective, a ship can be seen as a complex tool used by human operators to deliver services (Gernez et al. 2014), for example, the service of moving large quantities of cargo from one location to another. I define "ship operations" as the assembly of tasks performed by human operators, using the ship systems, in a sequence that enables the delivery of the ship's services. I define "ship architecture" as the assembly of systems on the ship that enables the human operators to perform the tasks required to deliver ship services. In this definition, the requirements for the design of ship systems include the need to develop and assemble these systems to address the needs of human operators performing ship operations.

In the next section, I review to what extent human-centered perspectives and methods have been presented in ship design research in relation to describing and designing for ship operations. Then, I present how the framework connecting ship operation and architecture was developed and how it works. I conclude with an evaluation of its functions, what is missing in the framework, and what opportunities for innovation it might open up.

2. Human operations in design for maritime industry

2.1. References to ship operation in ship design research

In the International Marine Design Conference's (IMDC) 2009 state-of-the-art review of models of ship design processes (Andrews et al. 2009), I found that 11 of the 27 presented models reference the operation of ships, primarily regarding requirements, for example,

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"requirements" (Heather 1993; Graham 1996), "functional requirements" (Andrews 1985; Tibbitts et al. 1993), and "operational requirements" (Andrews 1985; Burcher & Rydill 1995). Other references are made to "functional efficiency" (Andrews et al. 1996; Andrews & Dicks 1997), "reliability, maintainability, availability, and logistics" (Rawson 1986), "systems operating and upkeep philosophies," (Andrews 1985), and "maintenance philosophy" (Andrews 1985). Of these 11 mentions, seven give some indication of how to deal with ship operations in the design process: "perform need analysis" (Andrews 1985), "operational evaluation" (Heather 1993), "operational simulation" (Tibbitts et al. 1993), and "functional hierarchical decomposition" (Andrews & Dicks 1997). In a model referred to as "The Phases of Ship Design with the Push of Demand and the Pull of Constraints," Andrews (1985, 101) presents ship operations as demands and constraints embodied by different stakeholders in the design process ("Staff, User departments, Fleet, Fleet support, Lead Shipbuilders, Shipbuilders, Shipyards, Equipment industry"); this is the only example where ship operations are explicitly linked to the work of the ship's end-users.

The IMDC review from 2009 also mentions systems engineering methods, for instance, methods presented by Elliott and Deasley (2007). Such methods focus on the stakeholders of the design process and base this process on a capability statement and a requirement specification derived from user tests. However, it is unclear whether systems engineering methods are actually being used in the ship design community. Systems engineering methods are criticized by Andrews et al. (2009) for not providing the means to work with "the fundamentally creative elements of design." Levander (2003) observes that the systems engineering methods need better interfaces between subsystem blocks to create innovative designs.

In summary, the human-centric perspective on ship operations is not always included in ship design processes. When it is included, it is in terms of "requirements" that do not explicitly describe the needs of human operators. There are also few clear mechanisms for how to include these different requirements in the design process. In the HCD tradition, defining "requirements" implies entering into a process of exploring innovation opportunities. This process was originally modelled by Maher and Poon as a co-evolution of problem and solution (Maher 1994; Maher & Poon 1996) and was then used by Dorst and Cross (2001) in engineering design. I analyze this process in more detail in the discussion part of this article.

2.2. Human factors and implementing human-centered design principles in ship design

The human factors and engineering (HF&E) discipline focuses on what requirements will allow human operators to work in a safe and efficient way (Rothblum 2000; The Nautical Institute 2015). The first conference on the application of HF&E principles to the maritime industry occurred in 1977 (Anderson et al. 1977). These principles are now recognized by the International Maritime Organization, which recommends implementing them by following ISO standard 9241-210 (originally ISO 13407) (International Organization for Standardization 2014), thus formally introducing HCD to the maritime industry: "HCD is characterized as a design approach for usability supported by the discipline of human factors/ergonomics" (The Nautical Institute 2015).

In this definition, the HCD process centers around the notions of usability, context of use, and user experience. The process starts with "understanding the context of use" and then "defining the user requirements" followed by two sessions of "rapid prototyping" and "rapid testing" (The Nautical Institute 2015). None of these terms are present in the ship design process model review mentioned previously. Other references show some variation in the sequence and terminology, but they are based on the same principles (ASTM International 2013; American Bureau of Shipping 2014). Task analyses, user interviews, and field observations are cited as recommended methods for the analyzing user needs, and prototyping and evaluation are based on sketches, paper, and software mock-ups that are later reviewed with matter experts or are tested in the field.

The ISO, ASTM, and ABS standard and guidance notes focus on individual systems, but implementing this HF&E-driven HCD process on the scale of a ship design process is more complex: "It is only when the broad form of the [ship] layout has been finalized that issues relating to crewing, ship operations (...) tend to be investigated within the overall design constraints" (Andrews et al. 2006). One reason could be that naval architects are often not trained in working with human factors principles and methods. Of the 27 references in the IMDC review from 2009, "human factors" is mentioned once (Andrews 1998) as a part of management tools, grouped under project management issues and not connected to the scope of the ship design process. With a background in ship navigation and human factors, Lützhöft observed that "challenges include communication with project owners and the rest of the design team and making them aware of the importance of Human Factors" (The Nautical Institute 2015). In addition to being rare in ship design conversations, the topic of human factors might be diluted in the number of conversations taking place: "ensuring the ship is user-friendly starts with the overall concept produced by the naval architect, but is executed over time by many dispersed members of the design team" (The Nautical Institute 2015). There must be many stakeholders involved because the operational considerations grouped under the term "requirements" cover a wide range of expertise: "functional requirements with desired performance, regulatory and legal requirements, regulatory and safety constraints, owner's and user's demands, operational scenarios and constraints" (Nowacki 2009).

In summary, human factors provide both a process and some methods to capture and transfer operational requirements, at the system level yet theoretically applicable to the whole ship design process. However, the stakeholders driving this design process might not be used to working with these processes and methods and might not even consider them in the scope of their design project. When additional expertise is brought to the project, it is often late in the design process; it adds to the list of requirements to deal with, and it also adds to the number of stakeholders who need to work together to deal with these requirements.

2.3. Human-centered design practices in the field of human–computer interaction

Nordby and Lurås provide recent examples of research coming within the tradition of human–computer interaction (sometimes called human–machine interaction) and human factors as applied to the maritime industry and specifically to the design of ship bridges. Lurås and Nordby (2014) used field studies to experience and document the working conditions of ship crews. They also created representations of field insights that reuse competence and visual material from ship design; Nordby proposed a mapping technique based on a ship's 2D layout (Nordby et al. 2011), and Lurås proposed a scenario-mapping technique based on a task analysis (Lurås 2015). Finally, they proposed a model that frames how field studies contribute to design processes in the maritime industry (Lurås & Nordby 2015). The work presented in this article activates these processes, tools, and models, framing them as design activities that analyze how ships are operated in relation to their architecture.

2.4. Summary and reframing

With its traditional technology-centered perspective, ship design research lacks descriptions of how ships are operated by their crew and lacks design activities that connect the use of systems with the design of the systems, from the level of one human operator to the whole-ship level. Human factors approaches use a design process and methods that introduce a human-centered perspective to the design of ship systems. However, it seems that the conversations about human-centered operations of systems are often restricted to human factors specialists and are not consistently used throughout the ship design process. From this analysis, I derived the need for a set of methods and design activities assembled into a framework that would enable the following:

1) The introduction of human-centered ship operation into collaborative analyses taking place in the ship design processes.
2) The materialization of the relationships between human-centered ship operation and technology-centered ship architecture.
3) The use of this relationship-building process as a design activity in ship design processes.

3. Development of the OPAR framework

3.1. The ONSITE project

The Operation-Architecture (OPAR) framework was developed in the ONSITE project at the Oslo School of Architecture and Design. ONSITE aims to connect knowledge about ship operations with ship design processes by using field studies. ONSITE is a practice-based research project; the practice part consists of designing and carrying out field studies with the three industrial partners of the project, whereas the research part consists of analyzing how the performed field studies fit with the industrial partners' design processes. Table 1 presents the field studies performed in ONSITE that have served as support to the development of the OPAR design framework.

In each field study, the industrial partner owns the design process. The field researcher leads the definition of the field study scope and its execution. Workshops organized and facilitated by the field researcher are held before and after the field study together with the industrial partner to ensure that the study deliverables are aligned with the design process the study is informing. The field study results are handed over during a workshop that follows the study. I was the lead field researcher in all three field studies. The industrial partners also carried out field studies of their own; field study #2 was followed by a test of prototypes in the field, and field study #3 was preceded by another short field study and internal workshops to kick-start the ship design project. The ONSITE field study process is described in more detail as a process (Gernez & Nordby 2018a), a course (Gernez & Nordby 2018b), and a case study (Gernez et al. 2018).

The motivations for the research presented in this article come from the practice of field studies. Within this practice, I needed to describe the operations I observed on ships and to communicate these observations to the industrial partners I worked with. Because the field study process connects to the ship design process, I also needed to create a framework that would enable the integration of the field study data with the data used in the ship design process. This is a common challenge in field studies supporting design processes (Diggins & Tolmie 2003; Kujala et al. 2003).

3.2. OPAR framework development

I created the first version of the framework by putting together the three concept categories I was interested in: the ship design process, the outcome of the ship design process (i.e., the ship itself), and the use of the ship (which I called "operations"). From this first draft, I used two types of research activities to further develop the framework. First, the framework was tested by placing data in it. The available data I had consisted of early ship design data from one of the industrial partners of the project, for example, technical drawings of existing ships, a report of a preliminary field study on an existing ship, early specifications from customers, and pictures of sketches of ship concepts on a whiteboard. In this process, I looked at how the concept categories defined by the framework allowed the data to be sorted. For example, is it possible to place data in all the categories? Are there data that do not fit into one category or that fit into several?

Then, I looked at how this activity of placing data in concept categories might support a generative and evaluative design process; does it enable the generation and evaluation of design proposals? To facilitate this process, I used visual methods to show successive versions of the framework to present, discuss, and criticize them. This was carried out during internal review sessions with another researcher from the ONSITE project and during project seminars with all the ONSITE project industrial partners.

4. The OPAR framework

4.1. What it is and what it does

The framework is presented in Fig. 1. The targeted users of the framework are ship designers and other stakeholders of a design process. The framework consists of a two-dimensional matrix with four parts and four connections between each part. The vertical dimension of the matrix defines what relates to ship operation and what relates to ship architecture, as follows:

1) architecture is technology-centric and describes what systems are in place or are considered in the design process; and
2) operation is human-centric and describes how the users of the ship might interact with the ship systems.

Table 1 **Field studies carried out in the ONSITE project informing the presented research**

Field study #	Informing the design of	Design process owner: (industrial partner)	Field study focus	Field methods	Deliverable
1	Ship engine room	Engine room system integrator	User experience during maintenance of engine	User shadowing	Concept for a collaborative design process and collaboration tool to design human-centered engine rooms on ships
2	Ship surveyor portable support tool	Classification society with maritime consultancy services	Tasks performed by a ship surveyor during a ship inspection	User shadowing, semistructured interview	Task analysis, proposition, and evaluation of innovation concepts
3	Ship	Ship designer and builder	1. Ship operations 2. Test of new ship design concept	User shadowing, sketching, and prototyping	Mapping of operations and design guidelines for a new ship concept

The horizontal dimension of the matrix defines what relates to an existing situation in the design process and what relates to a hypothetical situation, as follows:

1) as-is: as it exists now, as described by current best practices; and
2) concept: as it could be, should be, or ought to be.

Using the framework consists of navigating between the four parts of the matrix to follow an analytic and generative design process. The division into four parts enables to identify what is known and unknown in terms of operation and architecture and to derive or evaluate new concepts based on this analysis. The framework indicates what design methods and activities can be used to navigate from one part to another. In the next section, I describe the methods I have used in the ONSITE cases to navigate the framework. This list of methods is not exhaustive, and other methods can be introduced. Reciprocally, the framework can be used to develop new methods that enable one to navigate it.

The dichotomy of operation/architecture is common in the human factors literature. Lützhöft observed how human operations adapt to the available architecture: "When designers do not take their views into account, users do adapt to the workplace when forced to, but adaptations and workarounds are signs that the design should have been better" (The Nautical Institute 2015). Lundh et al. (2011) observed how architecture influences operation and might lead to inappropriate operation and increased risks of crew injury.

The dichotomy of as-is/concept is traditional in design and has been used, for example, by Simon (1969), with descriptions by Evans (2014) of how design can be used to explore a future situation and by Krippendorff (2005) of how this is used by designers to challenge existing situations.

4.2. How does it do what it does: observations from our cases

In Figs. 2–12, I present a run-through of how the OPAR framework is designed to be used, with examples of use taken from the cases in the ONSITE project. The process is summarized in Table 2 at the end of this section. F2 – 12 T2

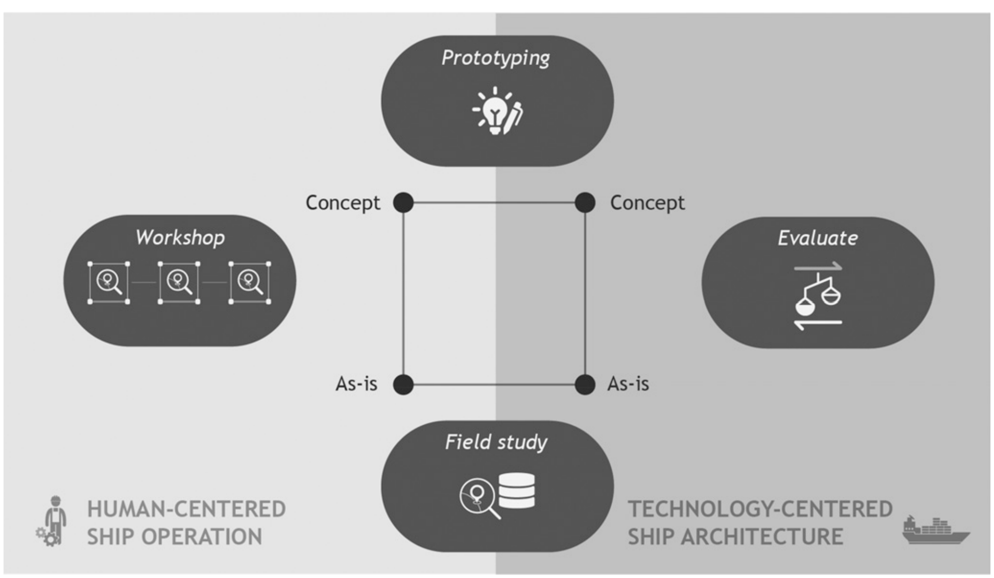

Fig. 1 The OPAR framework

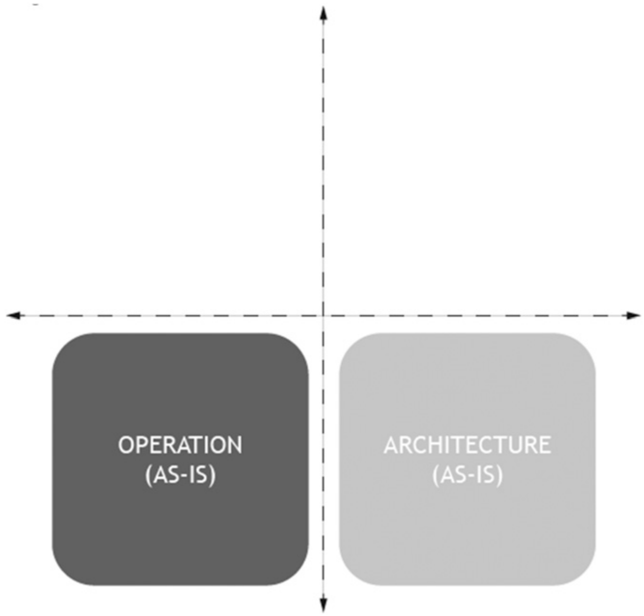

Fig. 2 Establishing a baseline

4.2.1. Establishing a baseline: current operation and current architecture. This is where most design processes start, by analyzing the current existing situation (Fig. 2). Visser observed that the reuse of knowledge from previous design projects is a central approach in design (Visser 2009). In ship design processes, ship designers often start by looking at similar existing ships, looking at 2D drawings of the ships. Such data show "how things are" (for example the layout of the ship), but do not necessarily show "how things work" (for example, how the crew might use the ship).

In the cases with the industrial partners of the ONSITE project, I used field studies on board ships to establish a baseline that described an existing situation in terms of ship architecture and ship operation. Maguire (2001) recommended using this method "when the situation is difficult for (the) user to describe in (an) interview." I used "shadowing" as one field observation method, where a user is followed when performing a work task. The observer records what the user is doing, what systems are used by the user, and what happens when the user uses the systems (Fig. 4). In other field observation methods, at each step, the user can be asked to explain what he or she is doing ("walk-through" method) or thinking ("think-aloud" method). The user can also be asked to sketch something to explain some concepts visually (Fig. 3). This can be combined with interviews before, during, and after the observation. The systems the users interact with are listed, and the interaction with them is described. The information collected can be mapped using journey mappings (which follow the actions of a user along a timeline). I also used 2D layout mappings to describe the systems present in a working environment.

The collected field data are mostly qualitative and are used to complement the background research carried out by ship designers; the understanding and experience of how ship systems are used by human operators are overlaid on top of data describing ship systems (such as 2D drawings). In the model of Lurås and Nordby (2014) of design-driven field research, experiencing life at sea is fundamental to improving the design judgment of designers, in terms of both the quality of idea generation and the evaluation.

4.2.2. Exploring the operational dimension: from current to future operation. This step (Fig. 5) focuses on the following questions: How do systems in place currently enable their users to perform their work tasks? How could the tasks be performed

Table 2 Summary of activities used in the ONSITE cases in relation to the OPAR framework

	Methods used	Data produced	Connections between operation and architecture
Existing architecture and operation	Search for similar ship	Ship drawings—2D general arrangement	Drawing does not show human operators' tasks or how they perform them
	Field study observations: Shadowing, walk-through, thinking aloud, interviews	Photos, videos, sketches, text observations of users in their working environment	As a whole, gives an understanding of tasks and how they are performed. Individual data can give more details about the user experience in using specific systems
Exploring new operation	Task analysis scenario mapping (layered-scenario mapping or a simpler version) Note: these methods are well suited for workshops, and they require field observations as input	Mapping of tasks performed by human operators, including how the tasks are performed, using what systems; also, observations of the user experience	The mapping gives an understanding of a whole sequence of tasks, so it gives a dynamic understanding of operations, i.e., how combinations of systems independently designed are used together by one user
Connecting new operation with new architecture	Sketching and prototyping: 2D sketching, 3D modelling, scenario mapping, paper/cardboard mock-ups, scenario enacting and filming	Sketches, prototypes in different forms. Evaluation of the sketches: Annotation on sketches, oral discussions, text descriptions	Visual representation of users and/or systems, often in a working environment. Enables facilitating a discussion about the match between the system functionality and the user needs. Immediate feedback by the user can be given when prototyping is carried out with the user
Evaluating new architecture	Not observed in our cases	Not observed in our cases	Not observed in our cases

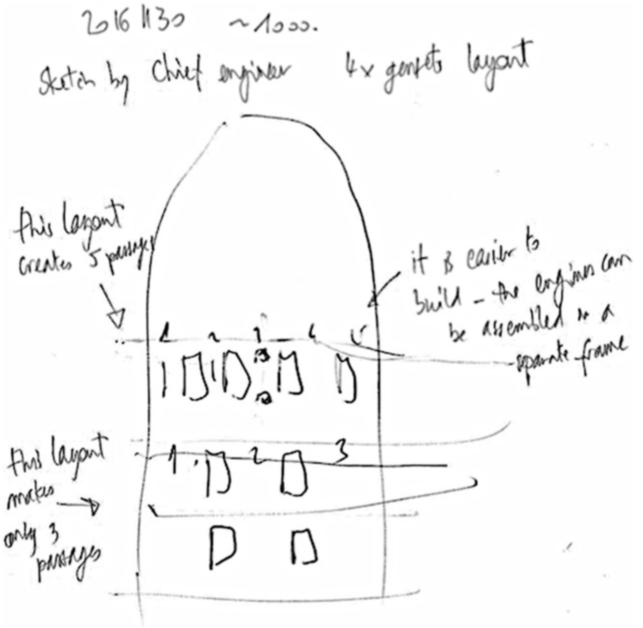

Fig. 3 Sketch of two possible engine layouts, done by a chief engineer during a field study. Sketch of two possible engine layouts, done by a chief engineer during a field study (hand-written notes are the author's)

Fig. 4 A crew member shows the narrow passage between two engines

otherwise by the user? What might this imply for the design of new systems?

In our cases, I used both task analysis (Kirwan & Ainsworth 1992) and layered-scenario mapping (Lurås 2015) to explore these questions. I used them to describe and analyze an existing (observed) situation before proposing potential design interventions, using a "zoom—intervention—problem" analysis technique (Sevaldson et al. 2012). Because technology-centered design processes might lack the terminology to describe and analyze the experience of human operators, I focused on participatory methods such as workshops, where I asked workshop participants to collaboratively 1) describe the current operation and 2) analyze what might be problematic to 3) agree on the needs for an improved operation. When design stakeholders from different companies participate in the same workshop, it creates the opportunity to discuss how the observed operational problems might be linked back to their respective design processes. This helps design stakeholders build ownership into the motivations, impacts, and importance of operational requirements. It also motivates the stakeholders to find a way to integrate these requirements early into their own design process, across their respective design processes, and into their respective companies and organizations.

I experienced such a case in field study #1 and described it in detail in another article (Gernez et al. 2018). For field study #3, I ran a workshop before the field study itself to gather the ship design team's knowledge of how current ship operations were performed; I used a simplified form of layered-scenario mapping (Fig. 6). I used a paper roll as a timeline and broke down an operation into small steps using sticky notes. For each step of the operation, I created hypotheses about what crew members might be involved in, what systems they might use, and how their actions might impact the safety and efficiency of the operation. The discussion was facilitated by 2D drawings of a ship, meaning that in effect, architecture data were translated into operation data. This mapping exercise also enabled the ship designers to identify what parts of the operations they were not familiar with and use this identification as a basis for scoping the subsequent field observations. The hypotheses set down on the scenario map were explored during the field study. After the field study, the scenario map was revisited and expanded with the field data; it was then used as a basis to generate and test new concepts regarding how to operate the ship differently and what requirements this change would create for new systems designed to enable this operation.

This type of scenario mapping enabled a new form of prototyping in the ship design process that did not involve 3D digital modeling or physical model building. This form of operation prototyping was absent from the ship designer's current design process, and the ship designers involved in that case deemed it useful and valuable.

4.2.3. Connecting operational and architectural concepts. This step (Fig. 7) focuses on finding technology-centered architectural solutions to the human-centered operational needs. This is carried out through sketching and prototyping, which are fundamental activities in design (Fallman 2003; Prats et al. 2009; Buxton 2010). I used prototyping to explore "how things work" to create situations where the experience of the user of a system can be analyzed. What matters is not the accuracy of the representation of the system, its user, or the user experience, but rather how the prototype enables us to analyze

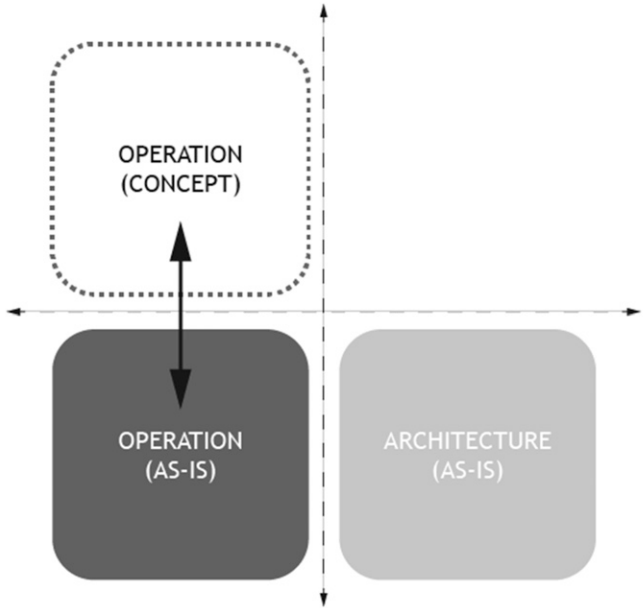

Fig. 5 Exploring the operational dimension

and evaluate the match between the system functionality and the user needs.

In the ONSITE cases, I worked with prototyping 1) during field studies and 2) following the field study in participatory workshops. I used sketching and prototyping activities such as 2D sketching, 3D modeling (Figs. 8 and 10), scenario mapping (Fig. 6), and paper/cardboard mock-ups (Fig. 11), as well as scenario enacting and filming (Fig. 9). The advantage of prototyping during a field study is that one has the opportunity to get immediate feedback from the user in its context of use.

4.2.4. Evaluating new architecture with regard to existing architecture. This step focuses on analyzing a potential new design from the perspective of its system architecture (Fig. 12). I did not go through this phase in the ONSITE cases. I propose that it could be carried out by comparing the new design with a previous iteration or with a design that was used as a starting point.

It is often the case in ship design that the design process is started by looking for ships of similar dimensions and capability and modifying these existing ships to reach a new design. In the language of the OPAR framework, this type of practice goes directly from an existing architecture to a new architecture without going through the three other steps that deal with human-centered operational considerations. The problem with this approach is that it propagates a whole design (both operation and architecture), including details that might not match human-centered operational requirements. This approach is often based on the use of "design spiral" ship design models, and it was criticized by Levander (2003): "this model easily locks the naval architect to his first assumption and he will patch and repair this first and only design concept rather than generate alternatives." In theory, using OPAR would help the design team uncover so-called "unknown unknowns" by combining conversations with visual thinking, and thus stimulating reflections. This discussion is developed in more detail

Fig. 6 Workshop before a field study, where the operation is mapped with sticky notes on a paper roll (bottom right corner) using 2D drawings of a ship to support the discussion

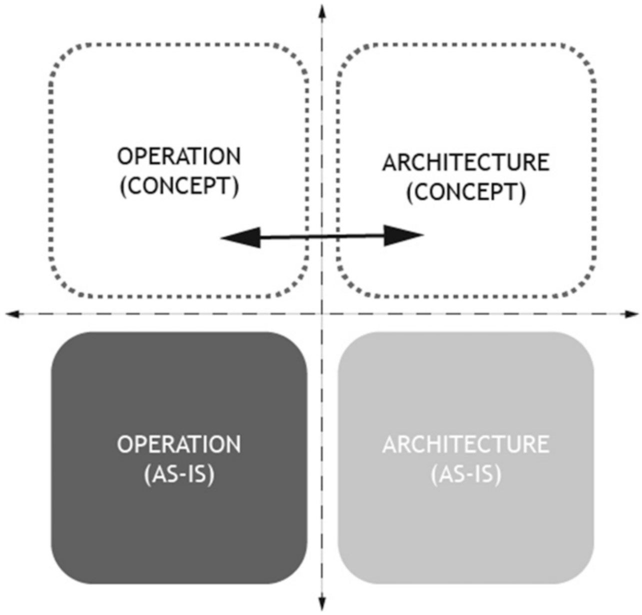

Fig. 7 Connecting operational and architectural concepts

in the discussion about the problem–solution coevolution model. F13 Table 2 and Fig. 13 summarize the methods used in the ONSITE cases in relation to the OPAR framework.

5. Discussion

I will discuss the use of the framework in a generic design process before evaluating how the framework addresses the three objectives defined in the introduction. I will also discuss what the framework lacks and what potential improvements would be interesting to research.

5.1. The functions of OPAR in a design process

As analyzed by Visser (2009), different forms of design activities and processes have a number of similarities. Design is a problem-solving activity, as originally formulated by Simon (1969), with the particularity that design problems are often ill-defined or wicked problems (Simon 1973; Rittel & Webber 1973). Working with such problems requires making a distinction between problem-setting and problem-solving (Schön 1983) or, as Buxton (2010) put it, respectively, "getting the right design" and "getting the design right." Coming from the field of computing science, Maher followed this line of thinking and proposed a model of problem-solving based on an iterative and interactive joint exploration of the problem space and the solution space (Maher 1994; Maher & Poon 1996).

In the context of this work, I propose to apply Maher's model of "problem–solution coevolution" to the two dimensions of ship architecture and ship operation; ship operation creates requirements that specify the problem space for which ship architecture solutions that satisfy these requirements need to be found. Maher's model has been applied to analyze a number of different design processes (Maher & Tang 2003) and to study creativity (Dorst & Cross 2001) and collaboration (Wiltschnig et al. 2013). A number of observations can be derived from the conclusions of these studies.

Defining the problem space: The first step of an exploratory design process consists of specifying and defining a problem space. I argue that the ship operation dimension should be used to specify the problem space. Doing so enables one to start the ship design process with the step of specifying a ship, based on the requirements of its future owner, in a conversation with the ship designer; this is also called the "requirements elucidation phase" (Andrews 2003b, 2011). In this phase, it is important to use human-centered methods,

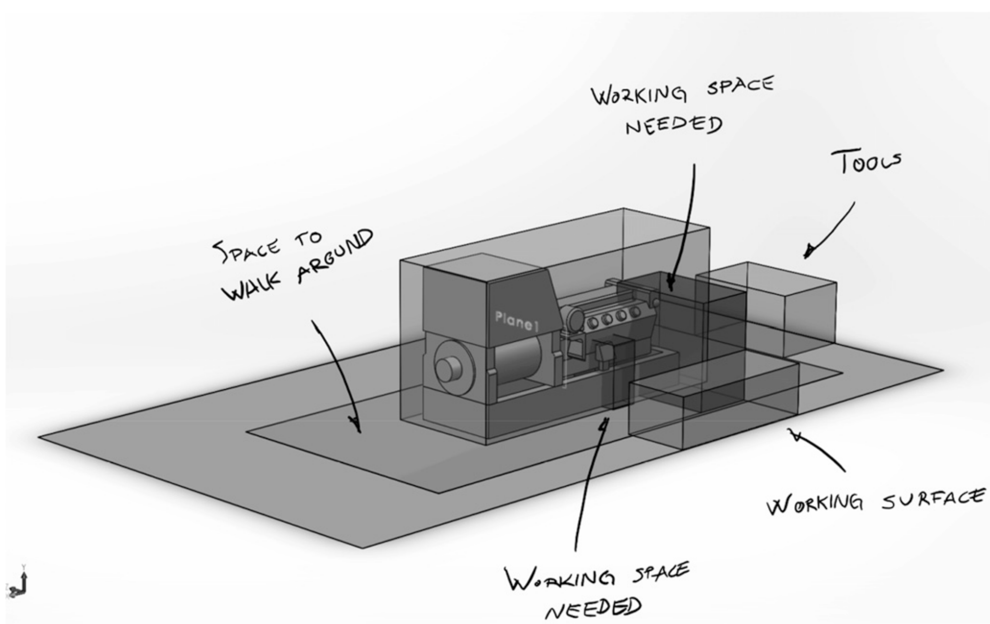

Fig. 8 Digital drawing used to prototype a concept developed after a field study and refined later in a participatory workshop

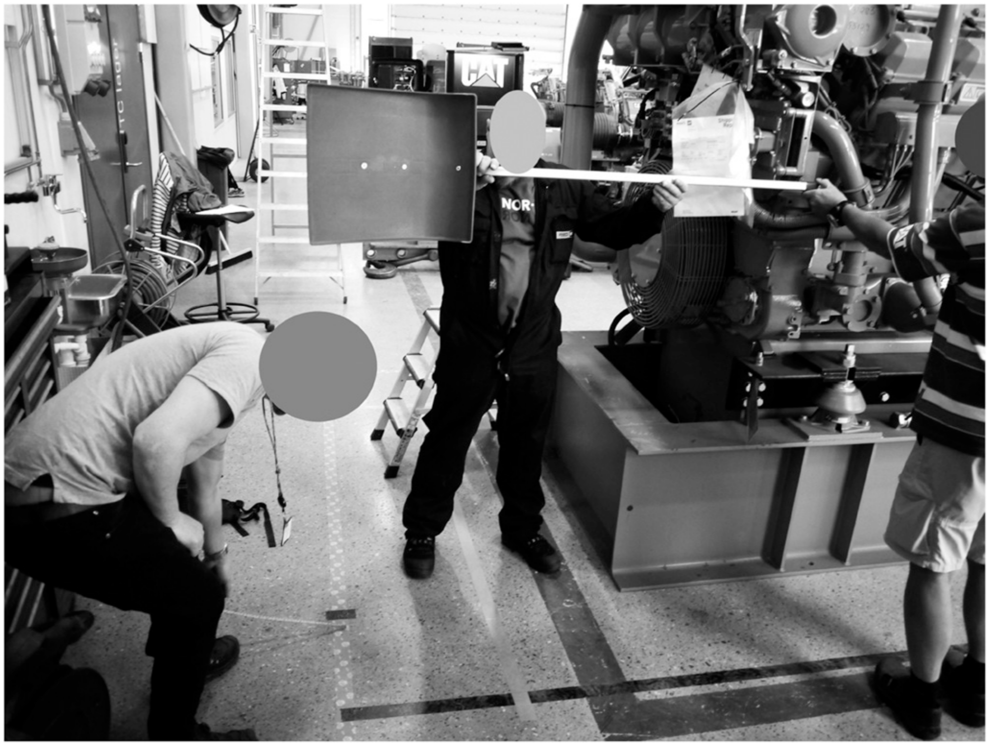

Fig. 9 Enacting engine servicing scenarios with props around an actual engine to inform a prototype of engine service space made in a 3D CAD program (see next Figure)

such as field observations, to include the requirements of the ship's end-users in the specification of the problem space. Failing to do so implies that the process would start with a problem space that might not contain the requirements necessary to achieve operational safety and efficiency and that this would thus lead to suboptimal solutions.

Exploring the solution space on the premises of the problem space: In Maher's model, "the design process iteratively searches each space using the other space as the basis for a fitness function when evaluating the alternatives" (Maher & Tang 2003). This means that not only do the ship operations need to be adapted to the functionalities offered by the ship architecture, but the ship architecture also needs to be evaluated with regard to how it might enable human operators to perform the daily tasks that constitute the ship operations.

Heuristics and transitions: Maher studied the cognitive activities used by designers when navigating inside and across the problem and solution spaces. In the problem space, these include adding and refining problem requirements, searching for new problem requirements, or reexamining existing problem requirements. In the solution space, these include drawings of solutions, evaluating solutions, and reasoning about the interactions between the current solution and its environment. Although the activities proposed by the OPAR framework seem to share some similarities with what Maher observed, it would be beneficial for the further development of OPAR to systematically explore what type of cognitive activities might enable a deeper, faster exploration of the operation and architecture spaces, with stronger connections among them.

Creativity when creating connections: Dorst & Cross (2001) observed that "a creative event occurs as the moment of insight at which a problem-solution pair is framed (…) Studies of expert and outstanding designers suggest that this framing ability is crucial to high-level performance in creative design." This means that the ability to connect human-centered operational requirements with technology-centered architecture solutions is fundamental and that this ability needs to be developed in the community of ship design.

Leadership and distributed competence: In their observations of collaborative teams, Wiltschnig et al. (2013) remarked that it was

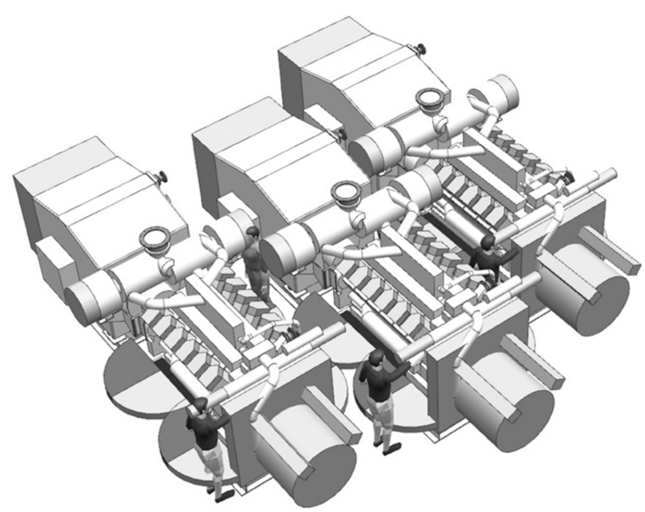

Fig. 10 Prototyping of an engine service space visualization using 3D CAD modeling based on a scenario-enacting session (see previous Figure)

Fig. 11 Prototyping using paper and cardboard during a field study

often the team leader who initiated design discussions by "mentioning or amending a design requirement." In the case of ship design, one could ask, what is the ability of the naval architect, who would be more at ease working with the solutions space in the architecture dimension, to revisit requirements in the operation space? What is the ability of a human factors expert, who would be more at ease working with the problem space in the operation dimension, to revisit requirements in the architecture space? What is their ability to work together to make connections between these two spaces? This implies that there is a need for facilitation and translation competences in the team, and the OPAR framework could help in training a team member for it.

5.2. Evaluation of the framework

5.2.1. Introducing human-centered ship operation into collaborative analyses in ship design processes. The OPAR framework introduces the notions of users, tasks, and use scenarios to describe the current state of ship operations and what might be other ways to perform these operations. These notions are introduced in the framework via recommended methods, such as field studies, task analysis, and scenario mapping. These methods are not new, nor is their use in a design process. In that sense, OPAR is built on known and practiced methods. However, these methods might be more familiar to human factors practitioners and industrial designers. OPAR places these methods as support methods by which to discuss other aspects of ship design that are more familiar to naval architects, ship designers, and systems engineers.

In summary, OPAR makes two moves:

1) It sets in the same place notions and methods that are familiar to different groups of users.
2) It gives equal importance to each group of notions and methods.

In the experience with the ONSITE cases, I observed that this second move is important. Although working together on the description of a design case, one of the informants, an engine room designer, explained that "designers [including this informant] are by all means aware of the working space when making their decisions. However, a working space is often looked upon as something static, and the ergonomic perspective is somehow neglected. For example, I consider an object that needs to be pulled out, but tend to overlook, or at least underestimate, the physical presence and movement of the persons surrounding that object in that particular operation."

5.2.2. Materializing relationships between human-centered ship operation and technology-centered ship architecture. Using the OPAR framework implies using methods that trigger the need for design teams to address questions that deal with operation and architecture, both from an existing and a future perspective:

1) Do the in-built functions of the ship match with what the ship is supposed to be able to do in connection with its business plan and initial specifications?
2) Are the tasks given to the users organized in a way that enables the users to perform the tasks?

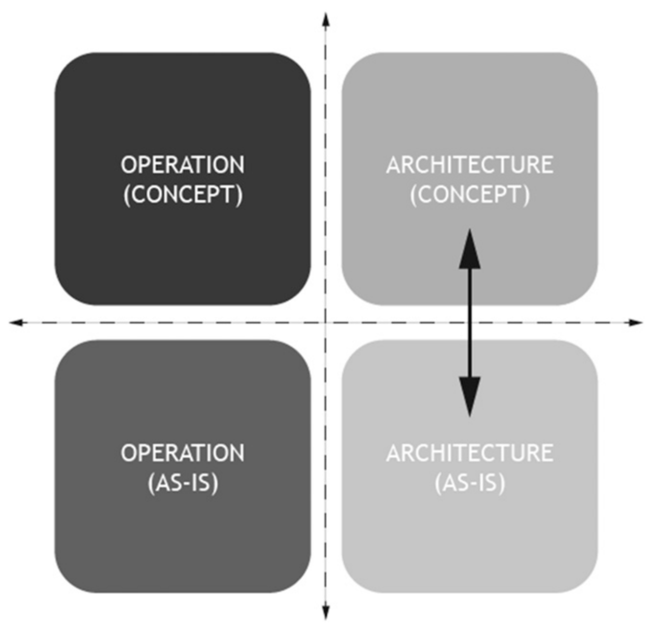

Fig. 12 Evaluating the new architecture

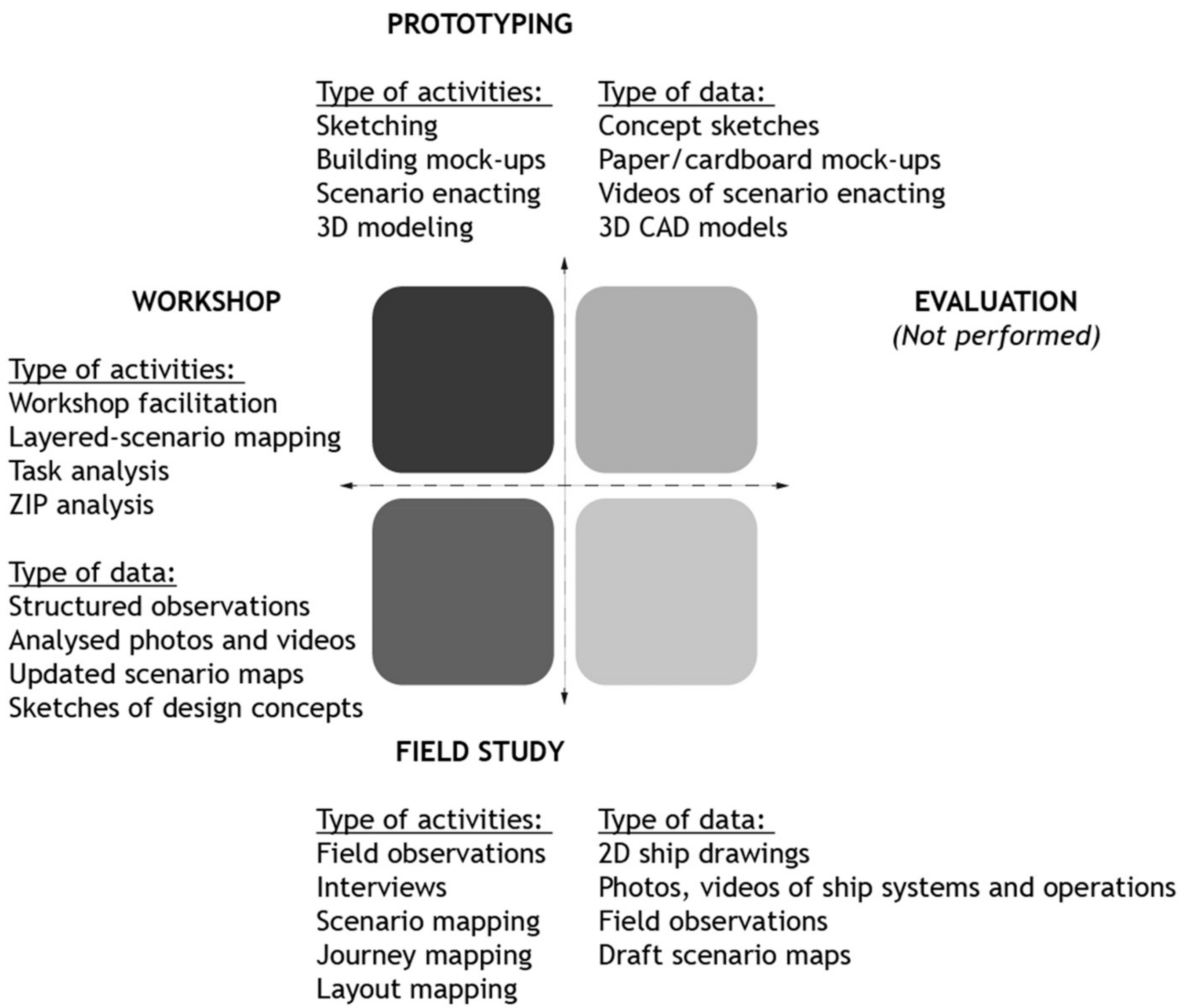

Fig. 13 Summary of methods and data used in the ONSITE cases in relation to the OPAR framework case

3) Does the ship have the systems and components that enable the users to perform their tasks to fulfill the functions of the ship?
4) Is the ship designed around a crew architecture and role distribution that enables the crew to use the systems on board to perform their tasks?
5) What is known about the operation and architecture, and how are they currently matched?
6) What information would be needed to create new operation and architecture concepts and new matches between operation and architecture?

The methods contained in OPAR generate a data output that connects operation with architecture. For example:

1) Task analysis methods describe how human operations are carried out, using what systems, and describing the experience of the user.
2) Scenario-mapping methods describe a sequence of tasks, which enables one to show how a variety of systems are used together, creating requirements for harmonization in the design of these systems instead of designing them as individual workstations.
3) Sketching and prototyping methods enable communication with other team members and ideally with end-users themselves about how a system could work and how a user might use it.

5.2.3. Building relationships between operation and architecture as a design activity in ship design processes. In terms of process, the use of OPAR is complementary to ship design processes and HCD processes originating from human factors. In terms of design activities, the use of OPAR generates data useful for ship design, for example, data traditionally used in ship design processes

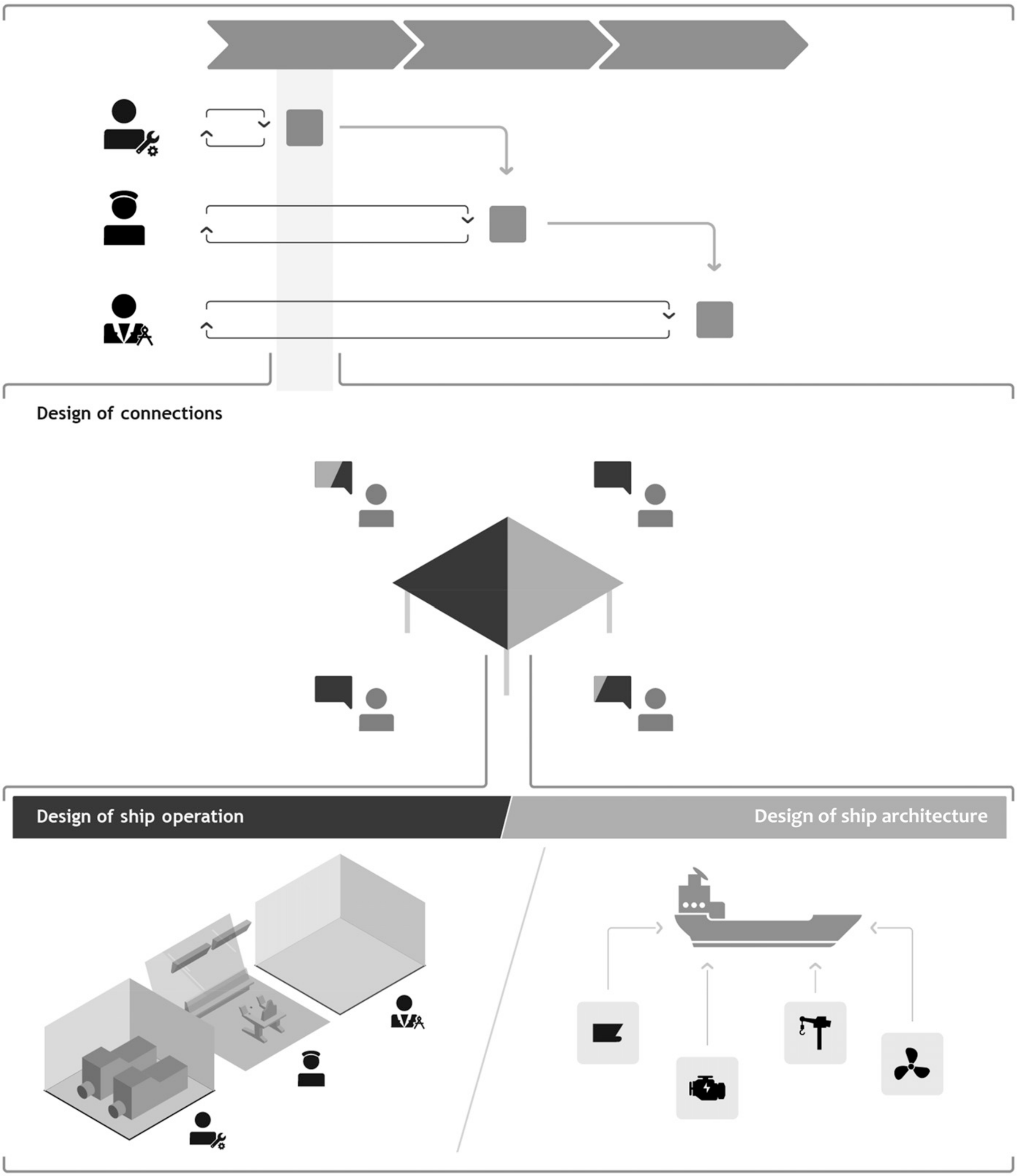

Fig. 14 OPAR as the basis for reframing ship design: a framework for designing connections between ship operation and architecture

(such as 2D drawings or 3D models), data that describes user experiences (for example, task analyses and scenario mappings), and data that supports creative processes (such as observations, reflections, sketches, and prototypes). OPAR is based on field experience, which influences design judgment. Using OPAR enables design teams to reflect on how the problem—operation space is specified and how the solution architecture—space fits with the problem space.

In summary, OPAR supports the three activities of the design-driven field research model proposed by Lurås and Nordby (2014): data collection, reflection, and experience. OPAR also extends this model from a single field researcher perspective to a team perspective and from the field study to the subsequent design process.

5.3. Further development

The cases carried out in the ONSITE project did not include the last part of the framework (evaluating new architecture). It would be interesting to study the handover from the team that works with field observations to the teams that work with design and engineering, if they are not already working with each other. I also assembled the framework through cases, and as a result, I have not been able to observe how to use it in continuity from the start of a design project.

I did not describe the "diagonal cases" of the use of OPAR in this article, which include 1) connecting existing operation with new architecture and 2) connecting existing architecture with new operation. The first one is actually a case of retrofit, for example, when systems or hardware are updated on board a ship that has been at sea for some time. I recommend first performing an analysis of the existing operation and architecture, to make sure the retrofit is designed to answer some specific needs. There also needs to be an evaluation of how to adapt the current operation to the retrofit and probably how to design a new form of operation based on the new architecture. The second case, for example, could be related to changing operational procedures on board an existing ship without changing its systems or hardware. In that case, this process can inform a future design process by highlighting the shortcomings of the existing one. It would be interesting to study how OPAR supports these two processes and what methods are suitable for use in these cases.

6. Conclusion: Implications for ship design

OPAR is a design framework that supports the conversations of design stakeholders from different disciplines around two main themes: human-centered ship operation and technology-centered ship architecture. For this conversation to happen, there is a need to reframe the whole ship design process as a HCD process based on a succession of interactions between ship design stakeholders.
F14 Figure 14 illustrates a proposal for such reframing.

Replacing OPAR at the center of this reframing implies understanding ship design as a three-fold activity:

1) the design of human-centered operations that enable the ship to perform as desired;
2) the design of an architecture that enables its operators to perform their operations; and
3) the design of connections between operation and architecture, between current and future situations, and between the design stakeholders involved in this overall multidisciplinary, collaborative process.

This reframing could potentially enable the following:

1) Replacing aspects that are traditionally considered project management issues at the center of the design process, for instance, which design stakeholders should be involved in the process and when and how they should be involved. This refers to the observation by Ulstein and Brett (2012) that the management of the ship design processes is critical to the outcome of the processes and that there is an identified lack of a process management layer in existing ship design processes.
2) Studying the operation of similar ships and exploring how to specifically design for operations. Andrews (2003a) refers to the challenges of building full-scale ship prototypes as one important problem that impacts the safety and efficiency of ship operations. Designing for operation would instead focus on exploring how ship systems are used and how their operation might impact safety and efficiency. Ship simulators are commonly used for this task, but they are expensive to use and are not modular. There seem to be interesting alternatives in the use of virtual and augmented reality technology, but only if they are part of a design framework (Kristiansen & Nordby 2013).
3) A more systematic focus on knowledge transfer between design stakeholders by stimulating their interaction and emphasizing the need to develop bridging approaches between different disciplines.

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IMPLEMENTING FIELD RESEARCH IN SHIP DESIGN

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SUMMARY

Human-centred field study methods in ship design projects have the potential to improve design processes, design data quality, personal experiences and design reflection in the field. Despite these advantages, such methods are not commonly used and there is a lack of detail describing how to implement them in maritime design. This contributes to creating a significant competence gap because the field study methodology originates from a domain not familiar to naval architects and maritime engineers. This study presents a process created for the practical step-by-step use of field studies. We describe the tasks to be performed by the design team, the input and output data created by the process and how collaboration will take place between team members going into the field and staying on land.

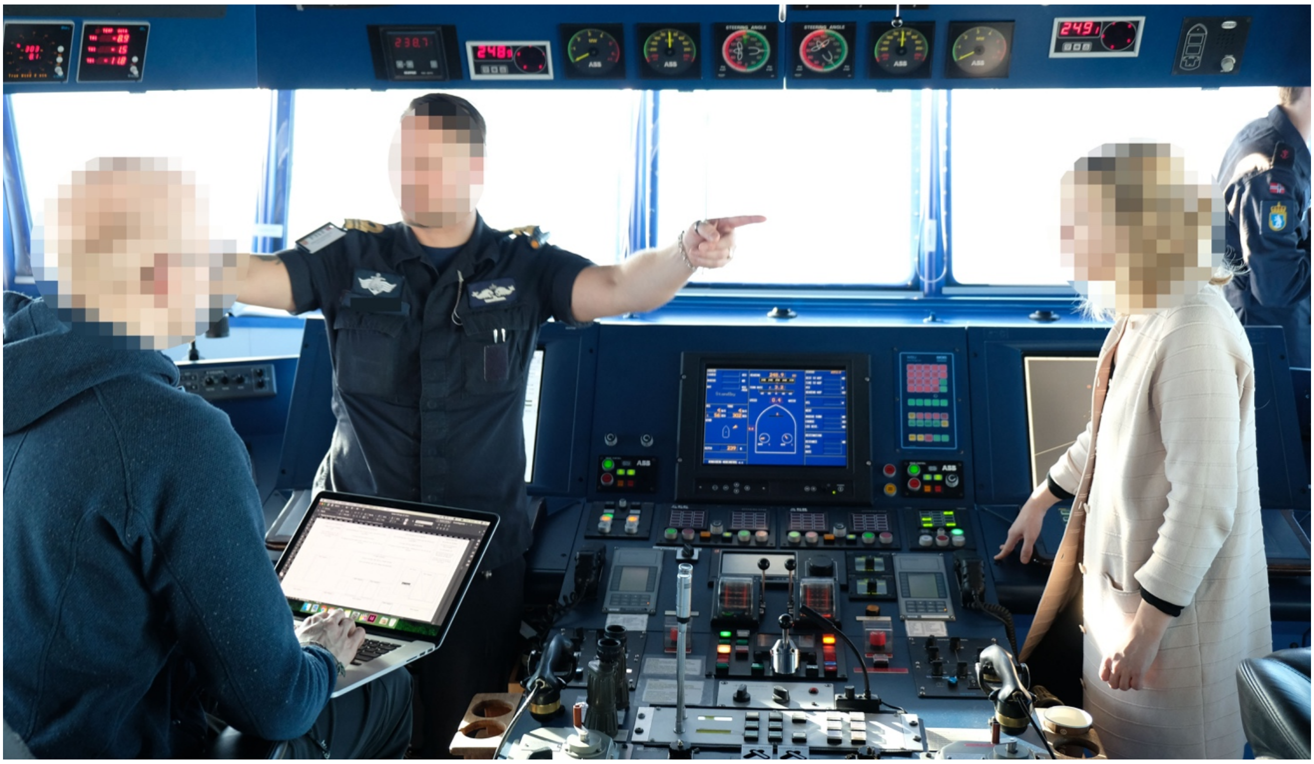

Figure 1 Two designers working with a bridge officer during a field study (The Oslo School of Architecture and Design).

1. INTRODUCTION

Human-centred design is increasingly seen as important in ship design (Gaspar et al. 2016; Gernez et al. 2018; Lurås and Nordby 2014, 2015; The Nautical Institute 2015). In order to realise such design processes, it is necessary to maintain knowledge about the ship crew´s experience of maritime operations. Some of this knowledge can be gathered on land, however, much of the complexity of maritime operations is difficult to understand on land. Field studies are a central part of human-centred design methods where designers go out on the field in order to better understand people and their activities (Figure 1). A suboptimal designed feature may trigger human error during ship operation (Rowley et al. 2006). Field studies create the opportunity to capture operator needs within the working environment, which can then be transferred to the ship design process. Working with field study methods provides the opportunity to better connect how ships are operated with how they are designed.

There is evidence that field study methods are beneficial to the design process in terms of user satisfaction and the effectivity of user requirements capture (Kujala 2003). Lurås and Nordby argued that the application of field study methods to maritime design processes enables the collection of data that would otherwise be impossible to capture; for instance, qualitative data pertaining to the experience of end-users in their context of use (Lurås and Nordby 2014). A designer working with field study methods also has the opportunity to experience the end-user's context of use and reflect upon it, strengthening the designer's judgment abilities (Lurås and Nordby 2015; Nelson and Stolterman 2003).

Field studies are not commonly applied in ship design processes today. A key challenge is the lack of frameworks for how to apply a field study to a multidisciplinary ship design process. In order to fill this gap, we explore the following questions: 1. What process might be designed to implement the field study methodology in multidisciplinary ship design projects? 2. What might the practical use of this process entail for designers?

In the software industry, the large quantity of data produced, along with consumption of time and resources are challenges of implementing field study methodology (Kujala 2003; Kujala et al. 2003). This means that the field study process needs to be effective in producing the desired results, and that the results are readily usable in the design process. In other words, the field study should be considered a design activity that is fully integrated into the design process. This requires the following handovers, transitions and translations throughout the design process:

- The handover between team members who went into the field and those who did not.
- The transition between individual team member insights to insights shared by the whole team.
- The translation between qualitative and quantitative data (the qualitative description of a human operator's experiences using ship systems for example) and the quantitative requirements of the system design.
- The translation between a human-centred design process (such as the field study) and a technology-centred process (such as ship design).

The field study process needs to be efficient: the minimum amount of resources necessary to implement the process must be used. This requires the design and implementation of a data collection strategy that (1) only targets specific data, and (2) guarantees the quality of the collected data (Kujala et al. 2003; Millen 2000). It is also important to consider the additional benefits that can be achieved through the process in order to maximise the return on investment. Chipchase used the term 'soft deliverables' to describe the potential added value of a field study outside of its contractual scope (Chipchase 2017). Competence learning, insights and process for innovation, individual and team reflections, individual design ability and design judgments are some of the soft deliverables of utilising field study methodology.

Based on a combination of these observations and our own experience, we have summarised the implementation requirements under three categories: customer requirements capture, impact on safety and efficiency, and innovation (Table 1).

The next section of this paper will present the field study process we have designed in order to address these challenges and requirements.

This work has been developed through the research project ONSITE. Together with three industrial partners, this project was funded by the Norwegian Research Council. It is based on existing research pertaining to the use of field studies in general design practices in the context of the maritime industry (Kujala et al. 2003; Millen 2000; Lurås and Nordby 2014, 2015). ONSITE is a practice-based research project wherein field studies were designed and performed. This project informed research about the tools and representations used to communicate and teach the field study process. This research was collaborative and involved two design researchers, a design student, two computer scientists and the ONSITE project committee with three representatives of the maritime industry. Research activities involved sketching and visualising processes and concepts, describing the processes and concepts in a project wiki, and regular project meetings. The field study process was then taught to design students during a 10-day course (Gernez and Nordby 2018).

Table 1: Summary of requirements for the process implementing the field study methodology.

Type of requirement	Specific requirements
Customer requirements capture	Connection operation-design is implemented • By capturing end-user needs • By transferring them into the design process
Impact on safety and efficiency	All of the above requirements, rephrased as "qualitative field observations are translated into operational requirements"
Innovation	Process is effective and efficient, justifying its cost and use in a design process Process connects with existing design processes Process supports and encourages multi-disciplinary communication and collaboration Process creates more value than the value of its individual deliverables

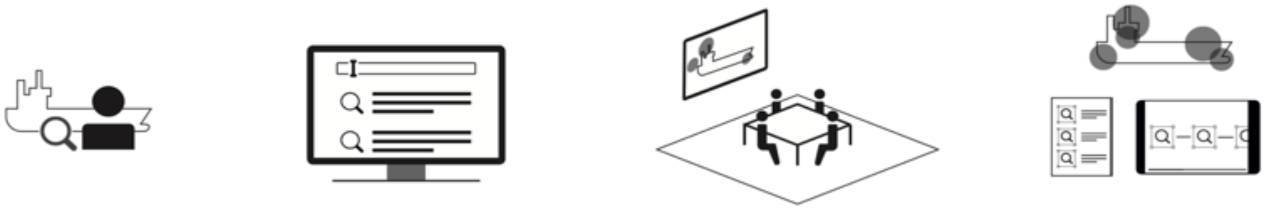

Figure 2: The ONSITE process in four steps: field study, data entry and analysis, collaborative data analysis, dissemination.

2. THE ONSITE FIELD STUDY PROCESS

The process consists of four main steps, beginning with the field study itself. This is followed by the processing, analysis and dissemination of the findings from the field study (Figure 2).

Each step is described and visualized in Figure 6 toFigure 10. Before that,
Figure 3 and Figure 4 explain how to read the figures that follow in this section. A brief explanation of how to read the figures is listed here:

- Each box represents a task to be performed.
- Each task box is a container for methods that can be used to perform the task. The methods are not shown in these maps for clarity reasons, and a suggestive list of methods is given in the next section.
- The arrows pointing outward from a task box indicate the output created when the task is performed. The tool used to create this output is not indicated in these maps for clarity reasons, and a suggestive list of methods is given in the next section.

The position and sequence of the tasks indicate that:

- Tasks in the same column are meant to take place more or less simultaneously.
- Tasks that follow each other are meant to be carried out in that order.

The process is highly iterative. Performing a task may lead to go back in the process to perform a task that has already been done. This because the process is based on an iterative and reflective process, and that parts of the process may retrospectively inform the process as a whole. This follows a Hermeneutics approach (Figure 5).

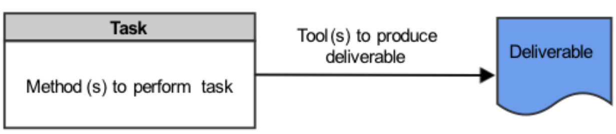

Figure 3: Mapping of the process: task, method, tool(s) and deliverable.

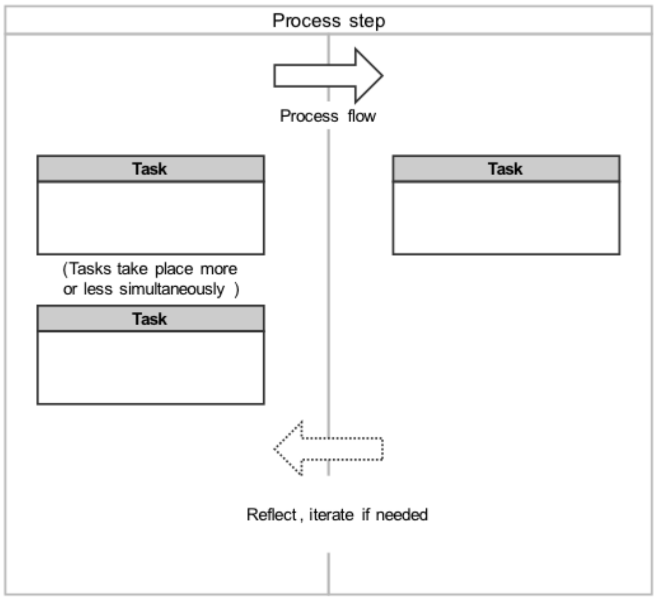

Figure 4: Position and sequence of tasks in the process mapping.

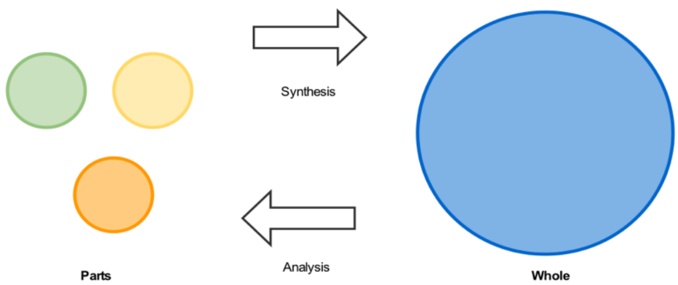

Figure 5: Visualisation of a Hermeneutics approach: an iterative analysis and synthesis to study a whole process and its parts.

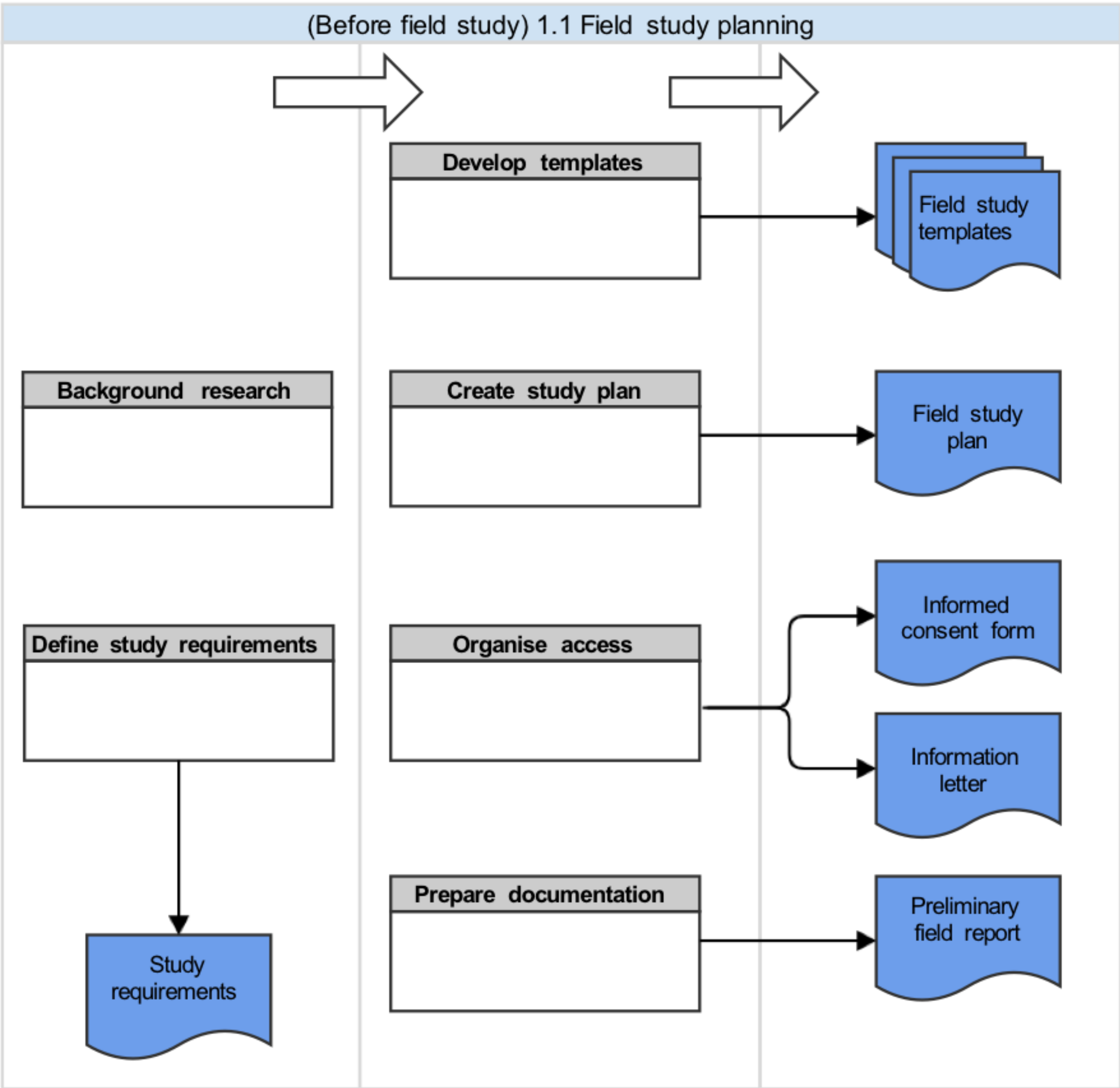

Figure 6: Step 1, Part 1: Field study planning

2.1 STEP 1: FIELD STUDY PLANNING

The first step involves the planning of the field study (Figure 6). The goal of this step is to design a field study that answers the needs of a specific design process. The top-down approach proposed by Kujala is used in this step, as it was also done by Lurås and Nordby (Lurås and Nordby 2015; Kujala et al. 2003).

Planning:

- Define the study requirements: based on the scope of the existing design process, define what the field study will focus on and how it will be executed at a high level.
- Perform background research: find information that helps to build a preliminary understanding of the users, as well as the user context you will meet in the field.
- Prepare the study:
  - Develop templates: design and produce templates that will help you to collect your observations and reflections in the field.
  - Create a study plan: create an observation plan and determine how to analyse and communicate it following the field study.
  - Organise access: find the person that can grant you access to the field and give you authority to observe and interact with informants in the field.
  - Prepare documentation: produce a preliminary field study report (layout and content) that shows how the field data will be analysed and communicated.

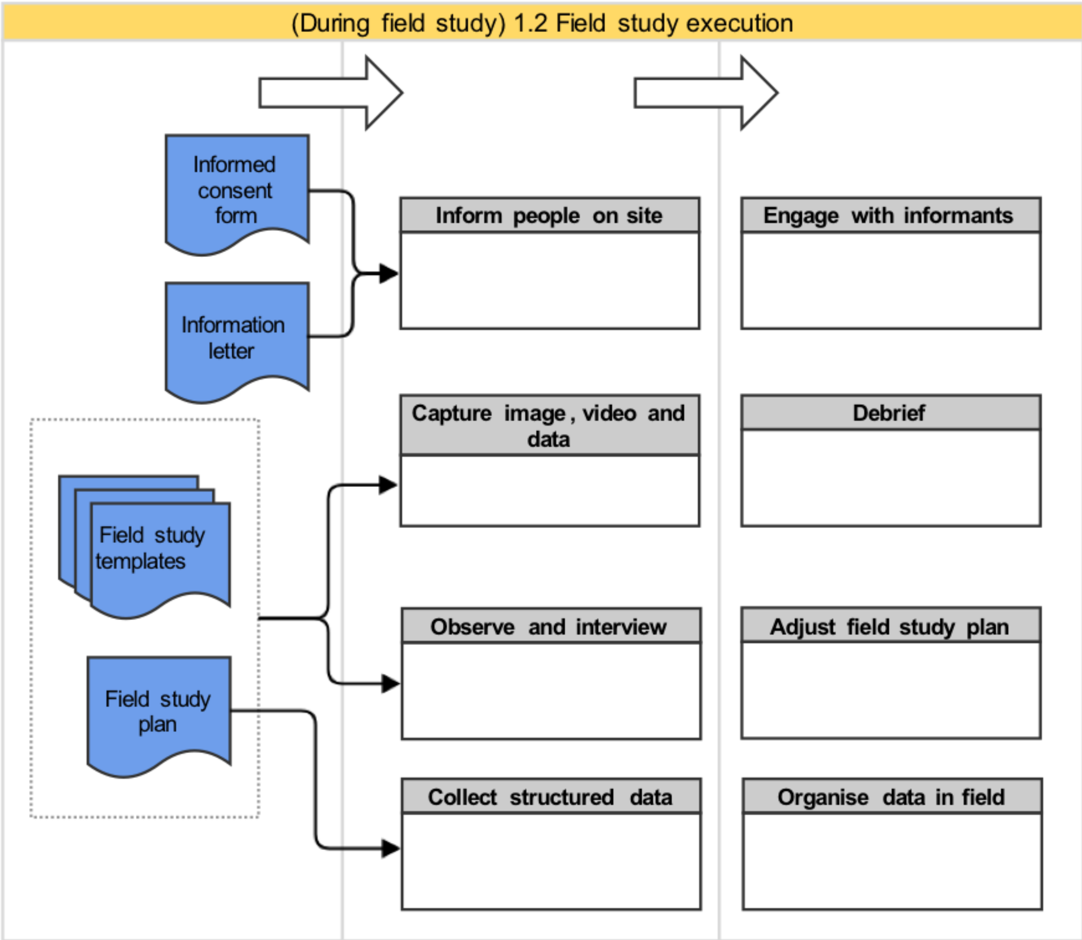

Figure 7: Step 1, Part 2: Field study execution

2.2 STEP 1 (CONTINUED): FIELD STUDY EXECUTION

Execution (Figure 7):

- Inform the participants on the site of the field study: produce an information letter that briefly explains the motivation, objective and plan of the field study. Also prepare for sharing the same content orally.
- Gather data:
    - Capture images, videos and data: decide what to document and how to do it. Be clear on the reasons for this decision. Train to ask for permission before capturing anything.
    - Observe and interview: explore a specific topic with an informant by asking questions and interacting with their work. While doing so, be respectful of the informant's work and privacy.
    - Collect structured data: in your hand-written notes, use codes that connect to the main field study objectives.

Execution (continued)

- Debrief: after each observation session, review the notes and summarise the most important observations. Write down follow-up questions and ideas for further observations.
- Organise data in the field: structure the collected data so that it is possible to come back to it at a later stage. Someone not familiar with the field study should be able to understand the data structure.
- Adjust the plan: assess what data still needs to be collected with regards to the initial field study plan. With this information, update the plan.
- Engage with informants: sketch ideas and concepts while interacting with informants or coming back to them after an observation session. Get them to sketch their own ideas and concepts.

2.3 STEP 2: DATA PROCESSING

This step consists of data entry and analysis (Figure 8) and takes place after the field study. The goal of this step is to transform the hand-written notes and media collected during the field study into a structured, digital set of data. The data should be structured according to the field study observation sessions and consist of observations and analyses. Part of the data analysis consists of producing a draft presentation of the temporary results of the field study. This follows Lurås´s 'design-driven field research model', and is designed to trigger a reflection over the study (Lurås and Nordby 2015).

Data entry:

- Write up observations: write up the hand-written observations into structured, clear, short, text-based observations.
- Review photo and video materials: review the photo and video material and select the ones that best communicate the observations.
- Anonymise text and media: remove all evidence of personal and private data in the text notes and media selection such as names and faces.

Data analysis:

- Sort data: make a list of topics describing the main findings based on the field study objectives, the summaries of findings prepared during the field study and the notes written up after the field study. Sort the individual observations under each topic. A tagging or coding system can be used.
- Analyse data: review the observations and media and add reflections: what ideas might this observation (or group of observations) trigger, and describe what problems, tasks or requirements might be derived from the process, as well as any further analysis that might be required.
- Summarise findings: prepare and share with the rest of the team a draft presentation of the field study objectives, summary of findings and observed problems illustrated by a selection of observations. Present the ideas and concepts as opportunities for change, modification and innovation in the observation situations.

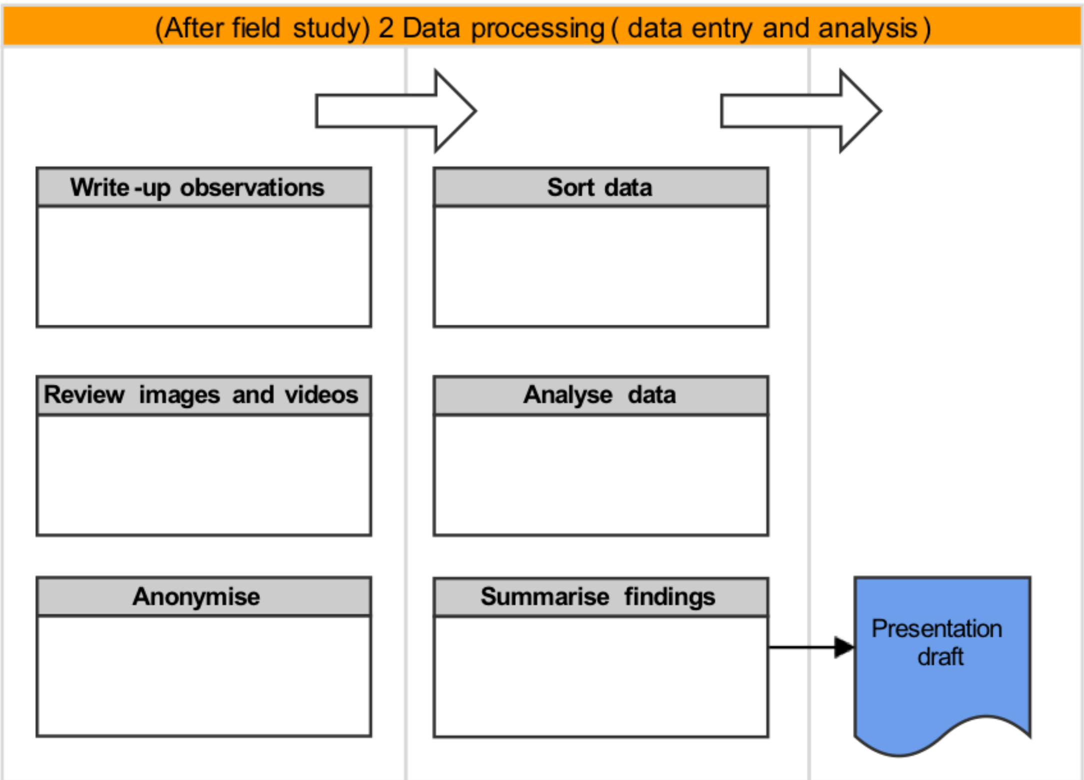

Figure 8: Step 2: Data processing after the field study

2.4 STEP 3: COLLABORATIVE DATA ANALYSIS WORKSHOP

The goal of this step is to prepare and facilitate a workshop with relevant team members and external participants where the field findings of both observations and innovation potential for are presented, discussed and critiqued (Figure 9). This type of workshop, referred to as a 'collaborative data analysis workshop', enables the removal of inherent personal observation bias (Millen 2000). It also anchors findings in the connected design process by reviewing them alongside design stakeholders who have not participated in the field study itself but have contributed in establishing the objectives of the field study.

Prepare the workshop:

- Define objectives: define the desired outcome of the workshop in line with the initial field study objectives and the findings of the field study.
- Prepare workshop material: produce templates and presentation material that enables the clear communication of the workshop objectives and facilitates participant contribution. Align the workshop material closely to the field study objectives. In doing so, what is produced during the workshop can readily be used within the design process.
- Recruit participants: reach out to individuals that have the expertise to contribute to the workshop and the mandate to champion the innovations produced by the field study.
- Prep participants: talk with a sample of the participants before the workshop to check the relevance of the workshop objectives, and to secure and build participant interest.
- Define roles: agree upon who will complete what task during the workshop. Examples of tasks to allocate during the workshop include sketching, presentation giving, time keeping, note keeping and video documenting.
- Test the workshop: perform a dry run with volunteers in order to test the workshop plan, material, timing and location.

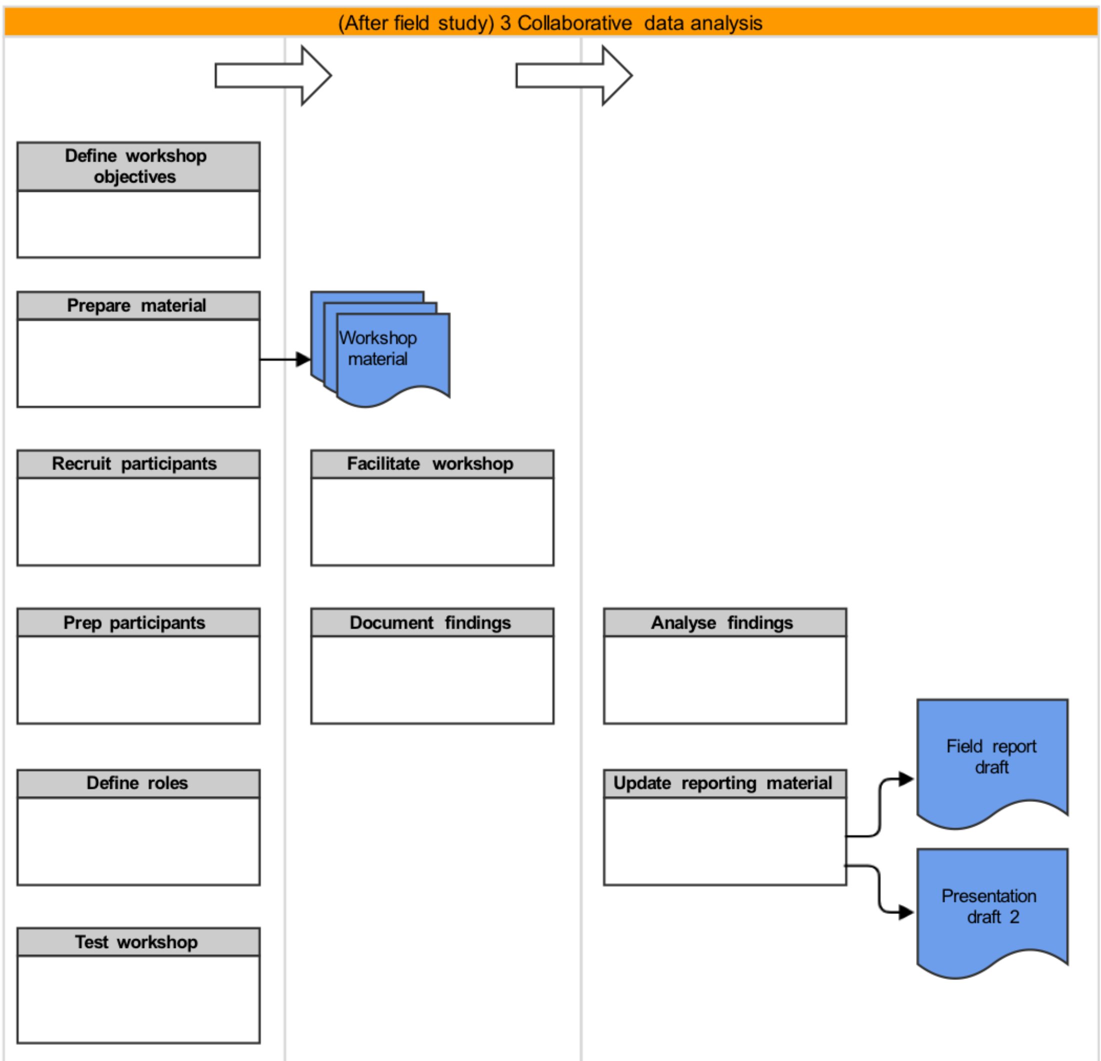

Figure 9: Step 3: Collaborative data analysis workshop

Run the workshop and its post-process:

- Facilitate the workshop: run the workshop as planned but leave room for improvisation to follow the group dynamic.
- Document workshop findings: collect observations and media from the workshop as if it were an additional observation session from the field study.
- Analyse workshop findings: reflect upon the observations and media from the workshop as done in the analysis step following the field study.
- Update reporting material: update the finding summary prepared at the end of the data analysis step following the field study.

2.5 STEP 4: AFTER THE FIELD STUDY: DELIVERABLES DISSEMINATION

The goal of this step is to update the reporting material already produced for the workshop, as well as produce and disseminate the final deliverables of the field study (Figure 10).

Dissemination:

- Prepare a dissemination strategy: identify the best suited individual to receive the field study results. Research how this person might disseminate the deliverables within their own organisation. Derive the best format for the deliverables and dissemination channel.
- Produce deliverables: produce material that communicates the field study objectives and details of the main study findings, including opportunities for change, modification and innovation. This may also include potential new findings from the collaborative data analysis workshop.
- Disseminate deliverables: while this step depends on the particular strategy, we recommend prioritizing a face-to-face presentation and handover of the deliverables. The strategy may also include a method of collecting feedback on the final deliverables, which would then require an update to the field study findings.

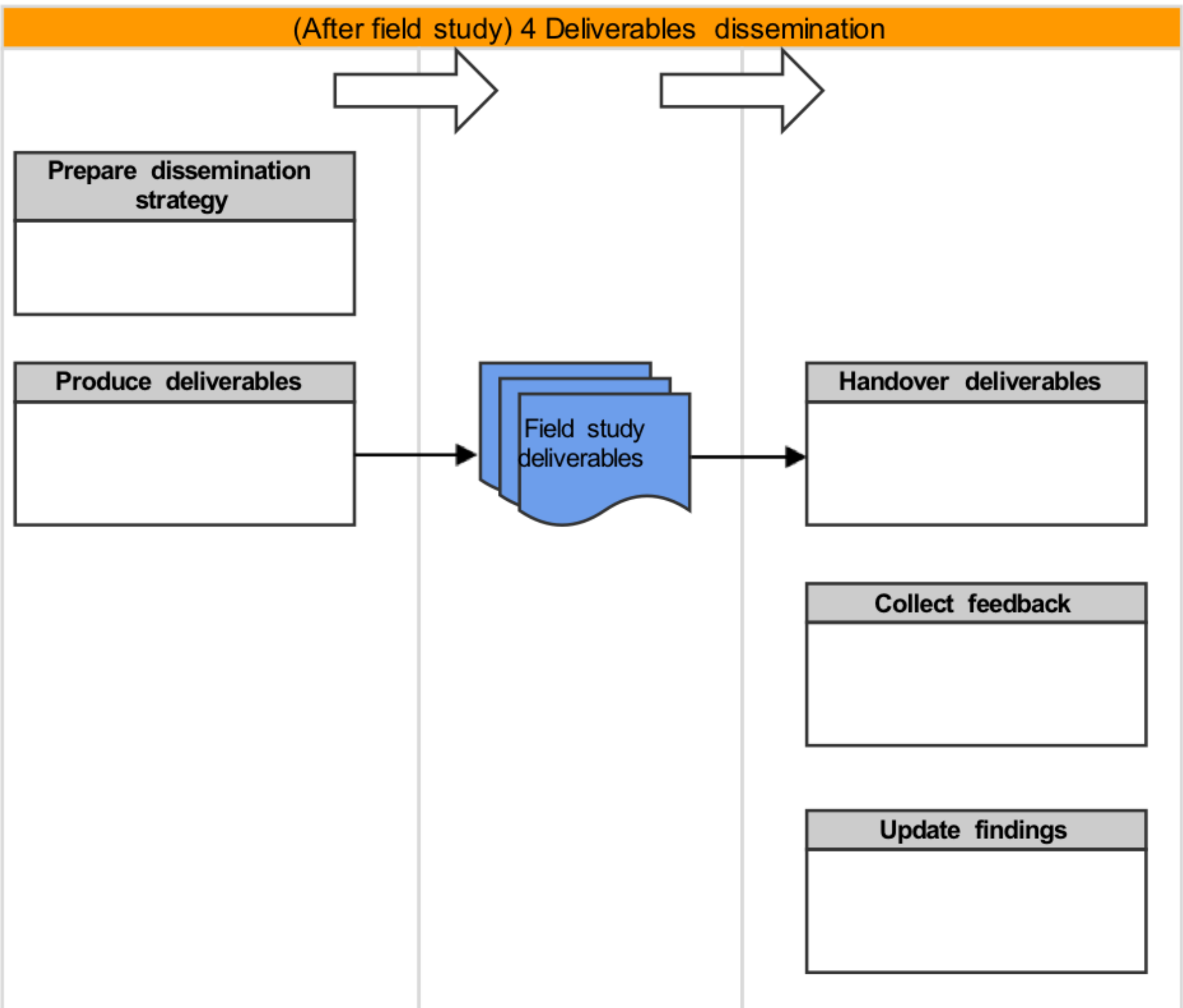

Figure 10: Step 4: Deliverables dissemination

3. ANALYSIS OF THE PROCESS

To further examine the process in detail, we analysed it in terms of steps and tasks, following an approach similar to a task analysis (Kirwan and Ainsworth 1992). The goal of this analysis was to study:

- The requirements to perform tasks and how they are performed.
- The deliverables created through the process, how they are created and how this helps the progression of the process.
- The types of data created through the process and their evolution.

3.1 TASKS, METHODS, TOOLS AND DELIVERABLES

A list of the deliverables produced in the process is presented in relation to the tasks that lead to their creation in Table 2. The tasks are shown, as well as suggestions for the use of appropriate methods in performing the different tasks.

Of the list of deliverables, specific deliverable types have been distinguished. Internal deliverables are used by the team in order to progress through the process and inform the different stakeholders involved. These are not shared outside of the team. These include:

- Design brief and study requirements.
- Field study plans.
- Information letters.
- Informed consent forms.
- Field report drafts.
- Presentation drafts.
- Workshop materials.
- Field study deliverables.

Table 2: List of deliverables.

Deliverable	**Produced by [Task]**	**Method suggestion to perform [Task]**	**Branches into [Task]**	**Method suggestion to perform [Task]**
Study requirements	Define study requirements	Workshop Design process mapping: Giga-mapping Journey mapping	Background research	Desktop research
Field study templates	Develop templates	Modify existing templates	Observe and interview Capture image, video and data	Shadowing Interviews Walk through Think aloud Artefact analysis
Field study plan	Create study plan	(No specific method)	Observe and interview Capture image, video and data Collect structured data	(Same as above)
Information letter	Organise access	(No specific method)	Inform people on site	Hold a presentation
Informed consent form	Organise access	(No specific method)	Inform people on site	(Same as above)
Preliminary field report	Prepare documentation	Use report template	Step 1.2: Field study execution	(See 'Observe and interview; Capture image, video and data')
Presentation draft	Summarise findings	ZIP analysis Task analysis Layered scenario mapping	Step 3: Collaborative finding analysis	Facilitate workshop Review and update findings
Workshop material	Prepare material	Modify existing templates	(All workshop tasks)	(Same as above)
Field report draft 2	Update reporting material	(No specific method)	Step 4: Deliverables dissemination	(No specific method)
Presentation draft 2	Update reporting material	(No specific method)	Step 4: Deliverables dissemination	(No specific method)
Field study deliverables	Produce deliverables	(No specific method)	Handover deliverables	(No specific method)

Depending on the case, the 'Field study deliverables' category may include several deliverables. For instance:

- Field reports.
- Presentations.
- Workshop materials.

Additional field study deliverables that are not mentioned in the table might include:

- Sketches and documentation of the ideation process.
- Curated image and video selections.
- Produced visual assets.

To make the process more efficient, a number of deliverables may be turned into templates and collected in a container that goes across individual field studies. These might include:

- "Field study templates": this refers to templates used for observation and note taking.
- Information letters.
- Consent forms.
- Reporting templates.

In Table 3, the types of suggested methods used to implement the field study process are presented. This list is non-exhaustive, and further guidance can be found by referring to the literature regarding ethnographic approaches in human computer interaction, and the implementation of human-centred design methods from the literature in human factors (Blomberg, Burrell, and Guest 2009; Chipchase 2017; Diggins and Tolmie 2003; Kujala et al. 2003; Maguire 2001; Nova 2015; Randall, Harper, and Rouncefield 2007).

There are no specific tools designed to support the execution of the field study process tasks. Schaathun et al. (2017) remark that existing software tools for qualitative research such as Computer Assisted Qualitative Data Analysis (CAQDAS) tools could be used for managing text-based and media field data. However, these tools require the user to be trained in academic research methods. These tools also do not support the collaborative and generative activities outlined in step 3 of the process, nor do they follow the dissemination needs of step 4. Standard office tools are generally used for all steps outlined in the process. This is an important limitation to the efficiency of the process, which is addressed in greater detail within the 'Further research' section of this paper.

Table 3: List of suggested methods.

Type of method	**Suggested Method**	**Suggested Reference**
Process mapping		
	Giga-mapping	(Sevaldson 2011)
	Journey mapping	eg (Følstad, Kvale, and Halvorsrud 2014; Polaine, Løvlie, and Reason 2013)
Field observation		
	Observation	eg (Lipshitz, Montgomery, and Brehmer 2005)
	Shadowing	(Wasson 2000)
	Interviewing	eg (Kvale 1996)
	Walk through	eg (Stanton, Salmon, and Rafferty 2013)
	Think aloud	eg (Stanton, Salmon, and Rafferty 2013)
	Artefact analysis	(Rathje and Murphy 2001)
Data analysis		
	Collaborative analysis workshop	(Millen 2000)
	Task analysis	eg (Kirwan and Ainsworth 1992; Lafrenière 1996)
	Layered scenario mapping	(Lurås 2015)
	ZIP analysis	(Sevaldson et al. 2012)
Ideation		
	Sketching	eg (Buxton 2010)
	Prototyping	eg (Suchman, Trigg, and Blomberg 2002)

3.2 DATA TYPES AND DATA EVOLUTION

The task analysis enables the description of data types created in the process, along with and how they evolve throughout the different steps. Before the field study, the scope of the field study and the draft report are defined in step 1. This leads to sketching the types of data that will be gathered, as well as how the data will be organised. Figure 11 shows an example of mapping done as a scoping activity before a field study. The field study participants mapped their current understanding of a ship operation, in order to find out what specific information the field study should gather. The same mapping was updated after the field study.

During the field study (step 1), field researchers observe users in their context of use and write observations through hand-written notes (Figure 12). There is often a lot of information to process, and as a result, a number of observations are not written down in this step. The debriefing steps assist in capturing undocumented observations. Photos and videos are raw data at this point, and they are usually reviewed during the debriefing process to support post-observation note taking.

After the field study (step 2), hand-written notes are transferred to a digital format. This is a major evolution of the observational data:

- Observations are written in short, full sentences instead of notes.
- Reflections are added to comment on how these observations inform the field study.
- Categorical topics emerge based on the initial scope and review of the actual field data.

This process takes place within the data entry phase, and again in more depth within the data analysis phase.

From this point forward and until after the collaborative data analysis (step 3), the data progressively evolves from 'individual data', i.e. data collected and processed by one field researcher, to 'team data', i.e. several streams of individual data shared across the whole team. During this process, individual observations are enriched when they are discussed among individuals with differing competences and thought processes than the original field researcher. This leads to the creation of additional observations and reflections that are recorded and added to the original data set.

Figure 13 shows an example of presentation slide used in a collaborative data analysis workshop. The findings are communicated using a large format picture and text annotations indicating the type of problem observed.

Sharing and reviewing data takes place throughout dissemination (step 4). For instance, this occurs when there is a formal handover of field study results through presentation. The data types and their evolution throughout the process are presented in Table 4.

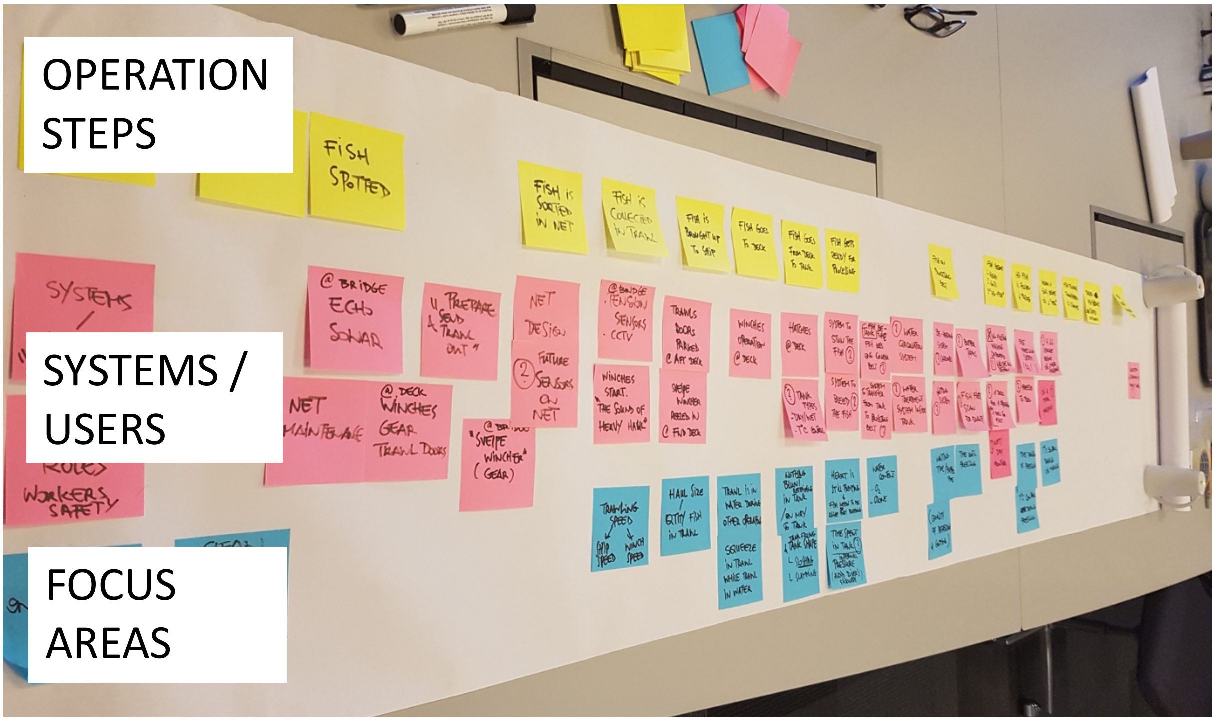

Figure 11 Step 1: scoping before a field study, using a mapping technique to agree on the type and structure of field data to collect. In this case: the steps of the operation to be observed and documented, what users are present at each step and

what systems they are using, and what should be the focus of the observation for each step. We used a colour code to differentiate the different type of information.

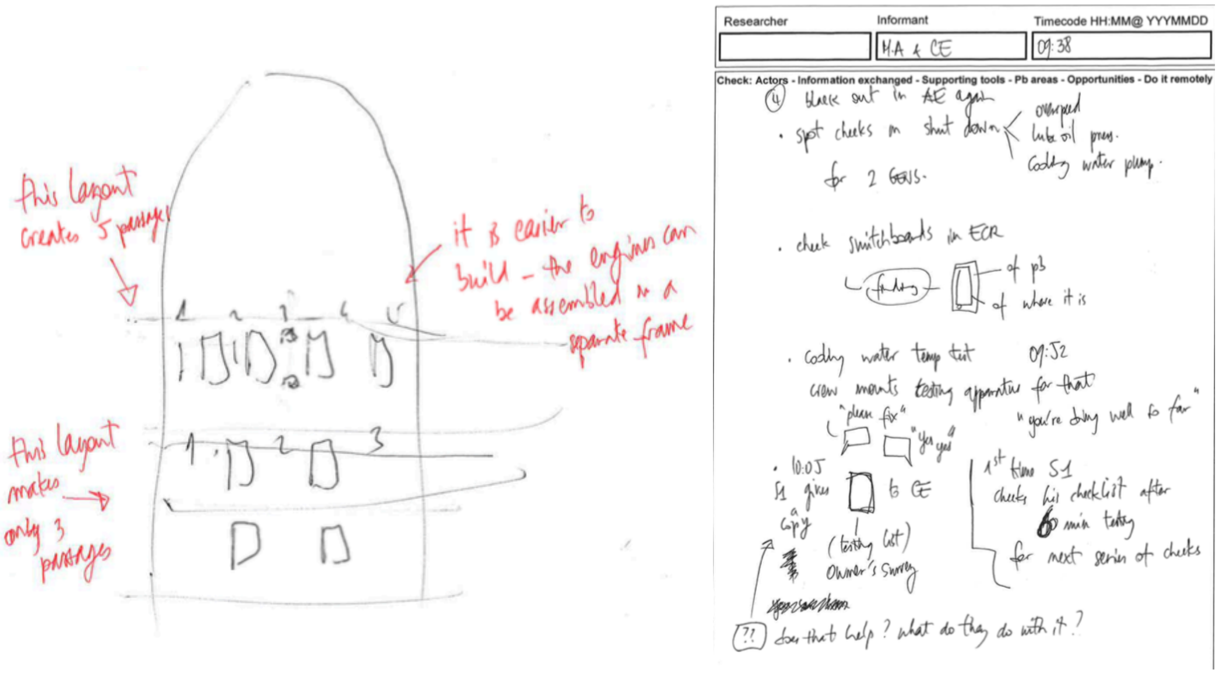

Figure 12 Step 1: (Left) sketch made by a chief engineer to explain the pros and cons of two different engines layout. The field researcher added the explanations to the sketch. (Right) example of hand-written notes from the field, using a template.

Figure 13 Step 3: example of presentation slide used in a collaborative data analysis workshop. In this case the observed scenario was the change of three oil filters on an engine.

Table 4: Data produced throughout the process.

Step	Data produced	Data type	Data container
1. Before and during field study	Hand-written observations	Analog unstructured raw field data	Paper notes
	Hand-written reflections	Analog unstructured raw field data	Paper notes
	Hand-drawn sketches	Analog unstructured raw field data	Paper notes
	Photo, video and audio	Unsorted media	Memory cards and data folders
2. Field data processing	Written up observations	Digital structured field data	Text documents
	Written up reflections	Digital structured field data	Text documents
	Sketches	Scanned sketch and clean digital version	Image file
	Selection of Photo, video and audio	Sorted anonymized media	Data folders (sorted)
3. Collaborative data analysis	Selection of written up observations	Digital structured field data	Workshop presentation
	Selection of written up reflections	Digital structured field data	Workshop presentation
	Review of observations and additional observations	Hand-written notes	Paper notes
	Review of reflections and additional observations	Hand-written notes	Paper notes
4. Dissemination	Selection of observations, reflections, sketches and media	Field study deliverable package	Presentation, report, folders with individual text and photo, video and audio files

3.3 STAKEHOLDER INVOLVEMENT

The stakeholders involved in the process are mapped at a high level in Table 5. This mapping shows the collaborative aspect of the process. It involves different stakeholders and it is recommended to use of a broad spectrum of competencies to enable the sufficient triangulation of data.

Table 5: Stakeholder involvement. X = involvement required, (X) = involvement recommended.

	1. Before field study	**1. During field study**	**2. Data entry**	**2. Data analysis**	**3. Collaborative data analysis workshop**	**4. Dissemination**
Field study leader	X	X	X	X	X	X
Team on field	(X)	X	X		X	(X)
Team on land	(X)			X	X	(X)
Owner of the design process informed by the field study	X	(X)			X	X
Field informants	(X)	X			(X)	(X)
External experts	(X)				X	(X)

4. DISCUSSION

Based on the above analysis, how the process addresses the requirements presented in Table 1 will now be discussed and summarised in Table 6.

In terms of "Customer requirements capture", the first step of the field study enables to connect operation with design by capturing end-user needs. The data captured in the field frames the end-user needs in their context of use. Further, the process enables to transfer end-user needs into the design process. The field study materials are created to be readily used in the design process straight after the field study (at the end of step 1). During data analysis (step 2), problem, task and requirement descriptions are derived from the field data. Task analyses and scenario mappings are used to describe and communicate the experience of end-users during specific operations. Finally, during the collaborative data analysis workshop (step3), the analysed data is reviewed and critiqued by a multidisciplinary team. Data uptake in the design process is discussed together with innovative concept reviews. Ship designers who participate in a field study have the opportunity to experience the user needs first-hand, which will influence their design judgement in the ship design process.

In terms of "Impact on safety and efficiency", the connection between operation and design is enabled through the translation of the field observations into operational requirements. This is implemented during the data analysis step where problem, task and requirement descriptions are derived. Safety and efficiency are always important priorities for ship designers in ship design processes. This means that a ship designer carrying out a field study will produce observations and reflections through the lens of safety and efficiency. Finally, during the collaborative data analysis workshop, data and experience can be debriefed with experts and compared against existing practices and regulations within safety and efficiency. In summary safety and efficiency will be best dealt with if they are part of the field study scope. If they are not, the assumption is that ship designers participating to the field study will place such items on top of their considerations.

In terms of "Innovation", the effectiveness and efficiency of the process stems from the scoping and planning phases of the field study (step 1). The scope of the study is established to answer the needs of an existing design process. The field study plan is designed to address these needs within the limited duration of the study. Data collection methods are selected in order to bringing the best quality of data. The connection of the field study process with existing design processes takes place during step 1. The process supports and encourages multi-disciplinary communication and collaboration, for instance during step 3 when workshop participants co-create a joint understanding and ownership of problems and solutions. Co-creation and common ownership opens to added value creation, introducing potential changes within decision-making, behaviour and culture in the organisations involved in the field study process.

Table 6: Summary of process tasks that address process requirements.

Type of requirement	Specific requirements	Step	Task
Customer requirements capture	Connection operation-design is implemented by capturing end-user needs	1	*Gather data, debrief and organise data in the field*
	Connection operation-design is implemented by transferring end-user needs into the design process	1	*Prepare documentation*
		2	*Data analysis*
		3	*Collaborative data analysis workshop*
Impact on safety and efficiency	All of the above requirements, rephrased as 'qualitative field observations are translated into operational requirements'	2	*Data analysis*
		3	*Collaborative data analysis workshop*
Innovation	Process is effective and efficient to justify its cost and use in a design process	1	*Define the study requirements, plan the study and gather data*
	Process connects with existing design processes	1	*Define the study requirements*
	Process supports and encourages multi-disciplinary communication and collaboration	3	*Collaborative data analysis workshop*
	Process creates more value than the value of its individual deliverables	3	*Collaborative data analysis workshop*
		4	*Dissemination*

5. CONCLUSION

The field study process we have been using in ship design processes has been presented in detail. The process builds upon existing research and is adapted to the specific needs of complex, multidisciplinary design processes.

The process is detailed step by step, showing the evolution of data generated by the process. The succession of tasks that need to be executed in order for the whole process to function have been discussed, and number of appropriate process methods have been suggested.

This analysis provides a deeper insight into how field study methodology can be used as part of ship design processes. It shows its iterative and multidisciplinary nature, as well as the necessity of having team members trained in human-centred design methods and human factor methods.

6. FUTURE RESEARCH

The lack of tools capable of managing data is an important limitation to the efficiency and scalability of the process. In conjunction with testing and documenting field study processes, the ONSITE project has explored the types of requirements that may assist in developing IT tools that support the process, as well as proposing strategies that address these requirements (Nordby et al. 2018; Schaathun et al. 2017).

An IT tool should be able to support the collection and modification of all data types produced throughout the process. This includes data entry, analysis and the production of reporting formats for the workshop and dissemination phases. This means that the IT system should be cloud-based, and that the main interface should be accessible through a web-browser reachable by different technologies (laptop, tablet or mobile). An offline version should also be developed in order to allow for the completion of work from locations with poor or no internet connection, as this may be the case on board a ship.

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A 10-DAY COURSE TO PLAN AND EXECUTE FIELD STUDIES FOR MARITIME DESIGN PROCESSES

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SUMMARY
Human-centred design processes often include field studies to achieve effective design solutions that support user needs. Despite this, field studies are rarely used in maritime design because they are time consuming and because it is hard to ensure that the field study outcome will have an impact on the design process. One way of overcoming these challenges is to better train designers in how to carry out efficient field studies aligned to the needs of ongoing design processes. We present a 10-day course to plan and execute field studies. The students' feedback indicates that the students are able to identify key challenges in their field study practice and propose solutions to address them. We conclude with propositions for how to improve the course and suggest to open it to a wide audience of designers and engineers with little or no experience with field studies.

1. INTRODUCTION

Field studies come from the ethnographic tradition of the human and social sciences (Blomberg et al., 2009). In such studies, field researchers live in the field together with field informants, often for an extended period of time. This enables the researchers to gain a first-hand personal, physical and transformational experience from which they can derive insights. Originally performed by ethnographers and anthropologists, field studies are now a regular part of human-centred design processes. Such processes, however, do not directly represent anthropology and are usually done in a much shorter time span and focused on specific design needs (Kujala et al., 2003). Because of this, field studies in design have been labelled 'ethnomethodology' (Button, 2000) or 'problem-oriented ethnography' (Lützhöft, 2004).

In a design process, field studies can create a deep understanding of a given group of users, their context and their tasks, so that products and services can be designed that will be more likely to be well understood, adopted and used to satisfy their needs (Kujala, 2003). There are, however, no guarantees that this will happen, and the specific impact of a field study on a design process cannot be known in advance. Field studies are time demanding, partly because they often generate a vast amount of (mostly qualitative) data that requires time to process. The ability to target specific data to be collected, to select a collection method that will capture this data with both high fidelity and time efficiency, and document the data efficiently are all important success factors of a field study.

The data collected in the field needs to undergo a transformation before becoming usable data for the design process. First, the insights collected are the result of the individual, physical experience of one designer. Individual insight becomes team insight after each designer has shared his or her experiences with the members of the design team, including those who have not been in the field. Team insights become data for the design process when it is connected to a specific user need in a specific context of use.

In addition, it is a challenge to organise a field study. Gaining access to the field and its informants requires time and good connections in order to build a relationship of trust and openness. Some contexts might be safety critical and require the field researcher to go through safety courses beforehand. Because of weather uncertainties, field studies on board ships can be delayed, and the field researcher might need to spend more time than originally planned on board the ship (Lurås et al., 2015).

We can summarise the challenges of using field study methodology as understanding how to gain access to the field and its informants, knowing how to obtain the right data, and doing so efficiently. Field data needs then to evolve from a personal and physical experience to team insights derived from collaborative reflection and analysis. In order to overcome these challenges, it is important that designers are properly trained and experience the entire process of planning and doing field studies for design processes for themselves.

2. THE COURSE

The goal of the 10-day field study course is to present the students with a method to deal with all the challenges of field study methodology. The course was developed as a part of the ONSITE research project in which we are designing and carrying out field studies with Norwegian maritime industrial partners. Partners include a ship design and building company, a company designing and assembling engine rooms for ships, and a safety and efficiency consultancy company. With the course, we transfer our experience with ONSITE and previous field studies in the maritime industry to the students (Lurås and Nordby, 2014, 2015).

Field studies are useful in the design process when they are time and resource efficient and built to deliver targeted opportunities for innovation that can be used in ongoing or new design processes. In order to deliver this quality, we have derived a set of guidelines for the field study planning process:

- *Human centeredness*: The field study aims to uncover user needs in a way that fully and ethically respects the privacy and integrity of the users.
- *Desired impact*: The process begins by agreeing with the customers about how the field study will contribute to competence building, innovation, and the design of a specific product or service.
- *Clear focus*: An agreement must be reached with the customers as to where the field study will take place and what will be observed there.
- *An implementation plan with room for improvisation*: The implementation plan contains instructions and directions enabling the researcher to improvise with confidence.
- *A strategy to communicate the field study observations*: The value of the field study lies in how insights are transferred. A significant share of the field study resources need to be allocated to this transfer.

We base the course content on the Lurås and Nordby model (Figure 1) of the three design activities embodied in the field study methodology:

- *Design proposal and reflection*: The students are asked to propose design concepts and present them in their final report.
- *Data collection*: Our set of guidelines touches upon the importance of documentation efficiency, and we introduce methods for efficient observation and documentation.
- *Field experience and reflection*: The students are given assignments that emphasize the importance of reflection as a significant part of their field experience.

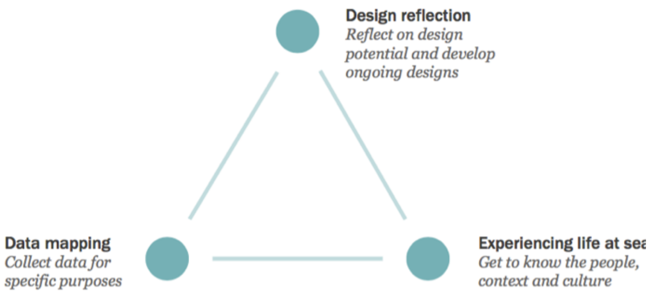

Figure 1: Lurås and Nordby´s design-driven field research model (reproduced with authorization from Lurås and Nordby, 2014).

Further, we base the course structure and learning activities on the experiential learning processes developed by Kolb (1984) modelled upon Schon´s (1983) and Dewey´s (1938) work on how experiences and reflections on experiences shape learning. The main idea is to arrange for learning activities that provide students with experiences and the opportunity to reflect about these experiences in order to help them assimilate the associated learning. Lurås and Nordby's model is designed to follow this type of learning process. For other examples, see the review by Tonkinwise (2005) on the use of reflective and learning processes in design.

We define the following learning objectives for the course:

- Understand the importance and ethical dimensions of field studies for design
- Learn to plan effective field studies
- Learn to use the most important observation methods
- Learn to reflect on design processes while in the field
- Learn to organise data from field studies
- Learn to analyse field data, individually and as a team
- Learn to share insights from field studies
- Learn to write field study reports

The course has been held so far for students in their third year of a master's program in design. For the 2016 and 2017 editions, we took a group of approximately 20 students on a passenger ferry ship. Ships with a regular route and schedule make the logistics of carrying out the course relatively easy and predictable. Passenger ships also provide many sites for observation, most of them not too technical, allowing students with no background in ship design and maritime engineering to collect insights. In addition, large ferry ships allow us to distribute many students across the ship without interfering too much with the ship's and crew's daily operations.
The course overview is visualized in the Figure 2 below. The content of each day is explained in the next sections, detailing the activities proposed to the students, what material they are given, what assignments they are given, and what material they are asked to produce.

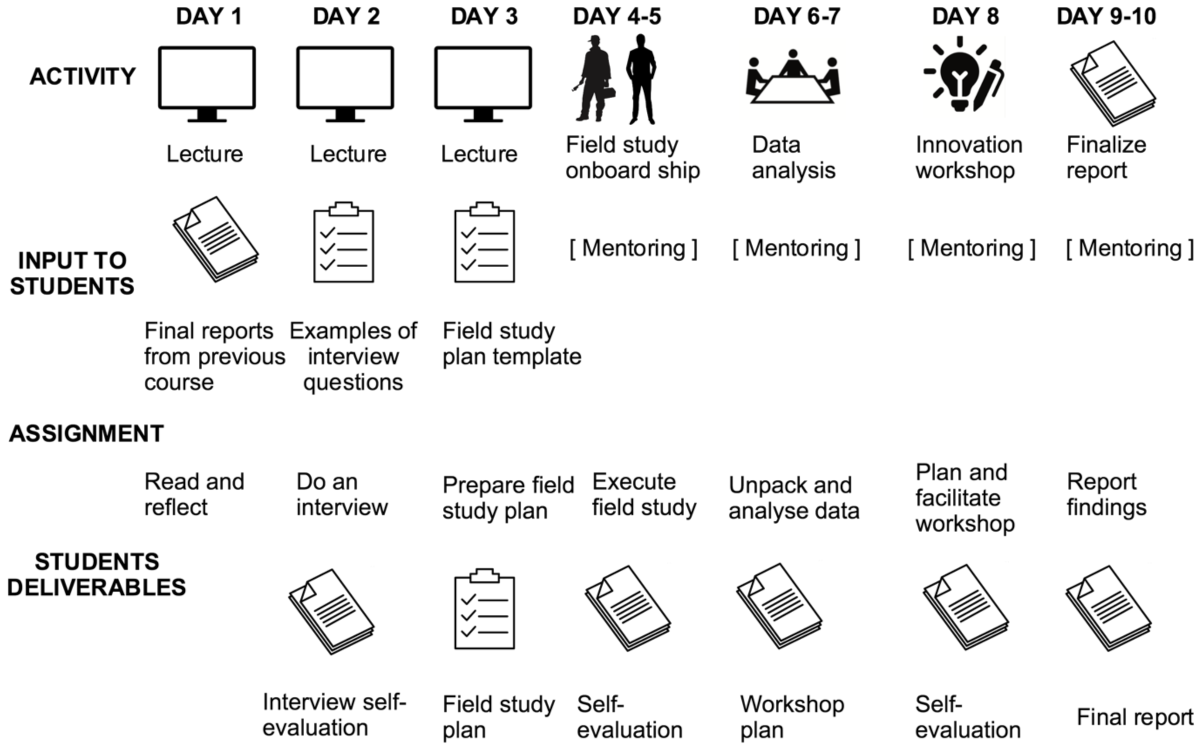

Figure 2: Overview of the day-by-day course activities.

2.1 DAY ONE – INTRODUCTION LECTURE

The first day began with a lecture where we shared our experience doing field studies on ships. The students were shown highlights from a design project that used field studies extensively (Lurås and Nordby, 2014). Using examples from this project, the students were introduced to the opportunities and challenges of sending designers into the field, sharing field insights among the design team, and collaboratively turning the insights into design objects. Examples of observations from the field were given along with ethical considerations regarding how these observations might be gained and used. We reminded the students that their work could have real economic consequences for the informants and for the companies involved.

The students were then given a selection of final reports produced by the students who took the course the year before. The objective was to give them an idea of what they would be able to produce at the end of the course and to make them aware of what type of final deliverable they would be asked to produce. The students were asked to read the reports and critique them in terms of what they thought was well done and communicated and what could have been improved upon.

2.2 DAY TWO – PROCESS AND METHODS

On the second day, we delved into the field study process and methods by way of a lecture. The field study process was covered in general terms and then in detail for each step. Observation methods such as ‘thinking aloud’, ‘artefact walkthrough’, ‘contextual inquiry’, and ‘context mapping’ were introduced. Finally, a specific lecture was given on interviewing techniques since mastering interviewing skills is a requirement for using most of the other field methods. In addition, interviews are very common in collaborative design and co-creation processes, so it is an important skill to practice.

The assignment for that day was to plan and perform a 30-minute audio-recorded interview with each other, which was then transcribed. Each student conducted and gave one interview. To ease the interview training, the students were asked to perform the interview in a familiar context where they do complex physical work. We used the school workshop as a location and context where the students were investigating how other students were using the facilities.

Importantly, after the interviews were done, the students were asked to listen to the audio again to evaluate themselves and ask: What went well? What did not? How could technique be improved? Both the transcript and the reflection are mandatory deliverables for the course.

2.3 DAY THREE – PRACTICAL ADVICE

The third day was the last day of lecture, and it focused on sharing very practical advice for how to go about field studies: how to get in touch with contacts that might provide access to the field, how to pitch the benefits of doing a field study to a potential customer, how to co-design and communicate the scope of the field study with a potential customer. Then, we reviewed the equipment to be taken into the field, how to prepare for note-taking, and how to rework the notes to capture insights. The students were given a number of digital templates that could be used in their study: a field study plan, a letter informing about the scope of the field study, an equipment checklist, a list of useful questions to ask during interviews on the field.

The assignment for this day was to prepare a field study plan and get ready for the upcoming field study. Arrangements had been made beforehand with a ship company to host the field study. The students were given templates of design briefs to help them define their desired focus for the field study, which could then be turned into a plan. We mentored the students regarding the elaboration of their plans; based on their interests, they were given tips on what to look at, and how to look at it.

2.4 DAYS FOUR AND FIVE – FIELD STUDY

The field study took place during these two days. This year, we boarded a passenger ship crossing from Norway and Sweden and returning the same day. The students spent approximately five hours on board. Together with the ship company, we identified beforehand areas of interests for the students: bridge, engine room, engine control room, kitchen, buffet restaurant, and duty-free shop. Two student groups looked at the 'customer experience' throughout the ship working. In most cases, it is best to use teams of two students so as to not overwhelm the users with too many field researchers observing and interacting with them. It is also best to make the students plan their individual roles during the field study: who will take notes, who will take pictures, who will ask questions.

The captain of the ship was aware of the field study and had given his green light beforehand. He knew where the students would be carrying out the field study, but he did not know exactly what they would be doing. The students were given the task of introducing their project to the ship's crew. They presented orally why they were there, what are they were interested in, what they needed from the crew. They also had the information in written form, ready to give to the crew if they requested it.

We were present during the field trip and stationed at one place on the ship, available to help and mentor the students. The students used the first half of the field study (Norway to Sweden) to perform a so-called explorative field study, where they familiarized themselves with the context and its users. On the second leg of the trip (Sweden to Norway), they focused on specific aspects and deepened their findings. After the field study, the students were asked to reflect on their experience and write a summary. This reflection is a mandatory deliverable.

In the past, our experience has been that students who choose to work from the bridge are the most likely to get sea sick because that is the highest point in the ship and where one is in constant eye contact with the sea. We therefore recommend to check the students' sensitivity to seasickness before allocating the focus areas. Some students this year got sick, but they still managed to record in audio most of what was happening around them while they were lying down, so they actually managed to collect very good data and work with it later on. Some students used seasickness tablets that made them a bit dizzy and reduced their ability to concentrate.

2.5 DAY SIX AND SEVEN – ANALYSIS

A short debriefing of the field study was done in plenum where students shared their experiences. Then the students were briefed and mentored in their analysis of their findings. During the rest of the day, we went from student group to student group to answer questions and give help. We observed that often the students had collected good material, but that it was challenging for them to assess the value of their findings and connect the findings to design problems. We tried to help them reflect over their findings and frame the design problems they wanted to work with.

The assignment for these two days was to prepare for a workshop where the findings would be communicated and worked on. The students were asked to deliver a plan for the workshop and prepare the materials for it including selecting and printing key visuals and creating new visuals specially designed for the workshop.

2.6 DAY EIGHT – WORKSHOP

Ideally, the workshop convenes the design team together with informants from the field and relevant stakeholders of the design process. The workshop is a very important step in a field study because it enables communication of individual field insights to the rest of the team, especially to the members who did not go on the field trip. It enables a collective review of the findings in order to validate and prioritize them, and it augments some of the most important findings with additional visualizations, ideas, and maybe even testing some ideas and sketching some prototypes.

For the course setup, it is a challenge to bring in field informants, and there is no specific design process connected to the field study. The workshops are held between two groups of students: one student group presents their findings the other group and invites them to collaborate in working with the findings; then the two groups swap roles. This way, the two most important 'post-field study' skills are being trained: transferring field knowledge inside a team and collaboratively working with the field knowledge. The students are asked to film their workshop for documentation purposes. We see both arranging the workshop and being a contributing part to an arranged workshop as important learning opportunities. The workshop format emphasizes the transfer of knowledge in field studies as not only recorded data, but as experiences that can be shared through conversation and collaboration. Again, the students were asked to write down and submit their reflections about their workshop experiences.

2.7 DAY NINE AND TEN – FINAL REPORT

For the last two days, the students prepared a report that assembled their findings and recommendations from the field. A suggested structure for the report is provided: (1) summary of findings (2) field study goals (3) field study methods (4) type of data collected (5) overview of the surveyed area with users and systems (6) observations and findings (7) framing of main findings with proposed innovation concepts.

We mentored the students throughout these two days. The final reports are submitted in Word format, and we usually share the reports with the ship owning company that granted access to their ship as a way to thank them.

3. COURSE EVALUATION

The objective of the course evaluation is to collect data about how the students experienced the course in order to improve structure and content. For example:

- Knowing what the students experienced as the most challenging aspect of the course helps us improve the course structure by prioritizing specific learning activities.
- Collecting input from the students on what they would propose as best practices for the field study methodology, based on their experience, helps us tailor the course content to this specific audience.

The course evaluation is based on collecting and analysing data about the experiences of the students. We collect two types of data:

- *Written reflections of students in text format:* The students are asked to reflect on specific learning activities and write down their reflections as part of course assignments. These reflections are submitted electronically through the school´s Course Management System (CMS), Moodle (Moodle, 2017)
- *Pictures and videos of the students performing the field study:* The students are asked to share all the pictures they took during their field study. They are also asked to video record and submit the workshops held after the field study.

The data set is built upon the three most fundamental activities for learning to plan and execute field studies: interview training on day three, field study on days four and five, and workshop on day seven. Extracts from the student reflections are translated from Norwegian into English. When needed, some quotes are slightly rephrased to be self-explanatory without needing additional context. The presented pictures are anonymised.

3.1 DATA ANALYSIS

We review the student´s written reflections against two perspectives:

- Challenges: What were the challenges identified by the students in this learning activity? This perspective helps us check to see if that what we think is challenging (and hence important to learn) matches the experience of the students. If yes, then it means that the learning activity is relevant and efficient and that the learning outcomes of the course are likely to be achieved.
- Best practices: Did the challenges identified by the students actually matter for delivering a high-quality field study process? This perspective helps us check whether or not the students have understood what makes the difference between good and bad practices. If yes, this means that the students are more likely to be on track with learning the fundamentals of field study methodology.

We review the picture-based data by looking for evidence of basic observation and documentation skills exhibited by the students.

3.2 EVALUATION RESULTS

3.2 (a) Interview training

The following types of challenges were observed by the students in this session of the course.

Getting the informant to talk:
‘I asked questions that gave me only yes or no answers’.
‘I could have talked less and commented less on the answers’.
‘I could hear myself finishing the informant’s sentences’.
‘I found it challenging to give my informant enough time to think about the question, and give more time after to come up with additional reflections’.

Asking relevant questions:
‘I felt my questions where not specific enough and that I had to rephrase them several times to get the type of answer I was looking for’.
‘I could have made my questions better adapted to the topic of the interview’.
‘I could have had several alternatives for follow-up questions’.

‘I asked a very open question: “What could be different?” […] I believe the answer I got would have been better had I had specified the relation to the parameter of my question’.
‘I felt I was not good enough at using my informant’s answers to progressively build more precise questions’.

Interview techniques, conversation facilitation material:
‘I tried a “walk and talk” technique during the interview, and that worked well; that provided me with the most complete answers of the interview’.
‘For the workshop, I sketched a map of where the interview took place and used it as a support to the interview. However, I could have planned better how to use the map in the interview’.

Planning and managing the interview:
‘I followed my list of questions quite closely, and that deteriorated the flow of the conversation’.
‘It did not feel natural to use ready-made questions from a template’.
‘I liked the flow of the conversation, but I was unsure how far I could follow my informant’s digressions with regards to my interview plan’.
‘I tried to rephrase the answers I got to confirm that I understood correctly, and that worked well’.
‘I tried to remember to tell my informant in the course of the interview that it was going well, that I was getting the information I needed, and to thank my informant for his/her time’.
‘I could have had a more specific goal for the interview’.
‘I could have focused my interview on a more specific problem’.

The examples show that listening to the interview recording made the students become immediately aware of important challenges that could help them improve their interview technique. For instance, how to interact with their informants, giving them time to think about and reflect on their answers, asking questions that progressively narrow down and deepen the topic, designing and using material to facilitate the conversation, and giving feedback to the informant. Based on our experience and on interview methodology literature (Kvale, 1996; Kvale and Brinkmann, 2009), all these identified challenges are very important success and quality factors.

3.2 (b) Field study

The following types of challenges were observed by the students.

Observation and documentation:
‘I was very happy with our observations because we managed very early on to spot interesting problem areas, which helped us make decisions for what to observe among the vast information available around us’.
‘It would have been more helpful to document a scene with video instead of photos. That would have shown the whole experience from A to Z, as well as how our informants behaved’.
‘We did not ask if we could record the interviews. We felt our informants would be more sceptical about participating and that it might impact their answers. I feel we should have tried anyways because it would have helped us better collect and process the data’.

Interaction with the informants:
‘Our informants needed further explanations about the goal of our field study and how they could help us do our field study’.
‘Our informants seemed to be at ease with our presence and our work. We explained to them first why we were here, what we planned on doing and how we planned on doing it. It seems that helped them relax’.
‘Our interviews looked more like conversations than structured interviews. We could have had more focus on what information we were trying to get from our informants’.

Overall planning and execution of the field study”
‘The informants we talked to were regular customers who had not exactly experienced the problem we were interested in solving’.
‘We stopped several times to go through our notes to update and refine the problem areas we had defined’.
‘It’s surprising how fast time goes’.
‘What was most important for me to learn was not the field study itself but rather the importance of being prepared both before and during the field study. … It’s been very educational to see how good preparations can improve the findings and the experience of the field study’.
‘The biggest challenge for me has been to define focus areas. However, it went quite well, thanks to a systematic review of our findings during the field study and mentoring from the course holders’.

The extracts above show that the students identified important success factors in line with our own experience, for instance, being very well prepared, being very clear with their informants, selecting the appropriate observation methods and the appropriate informants, and taking the time to review the findings while in the field.

Photos taken by students during field studies show some skills they were able to use during this learning activity (see Figures 3–6 below).

Figure 3: Interview of user in context.

Figure 4: Identifying a potential issue (trip and fall involving cooking objects in the kitchen).

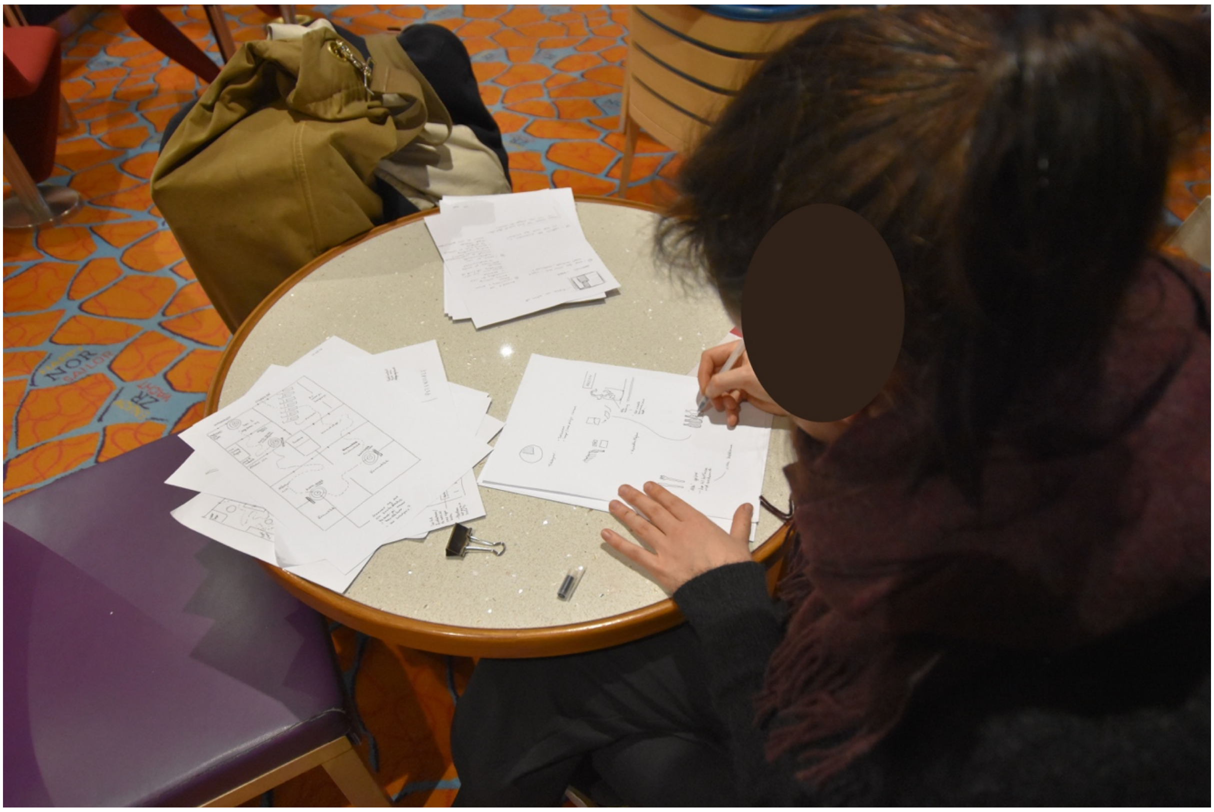

Figure 5: Reviewing notes and sketching while on the field.

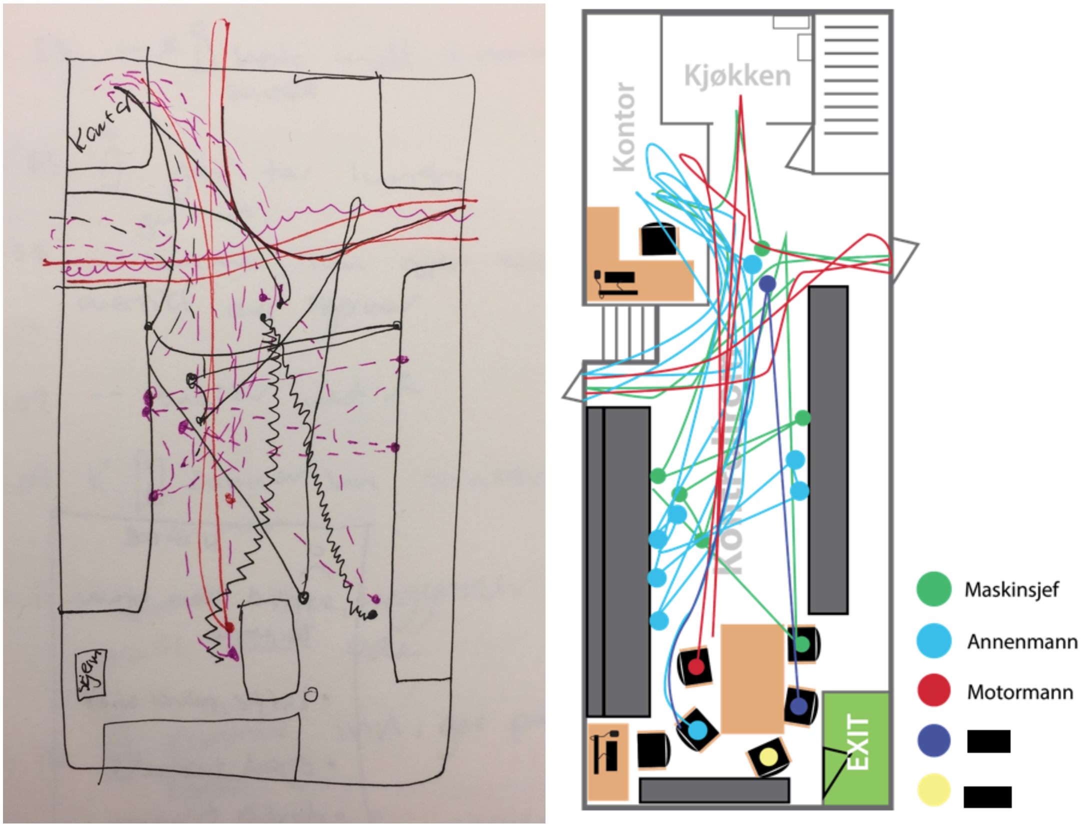

Figure 6: Sketching in the field (left) and output in field study report (right). The sketch is an attempt to document the movements of the users of an engine control room.

3.2 (c) Workshop

The following types of challenges were observed by the students.

Communicating field findings to team members who were not in the field:
'Putting forward to others what we found helped me see the big picture of our findings. It also helped us with deepening and consolidating the reasons we chose to focus on specific problem areas'.
'It was very useful and refreshing to talk to someone who could see our findings from a different perspective'.

Managing the engagement and participation in the workshop:
'Participants were initially interested in the problem areas we identified, but when we let the participants work with the problem areas by themselves, the motivation fell down'.
'We communicated very tightly defined problem areas. The workshop participants told us that they felt ideas were "created in their heads" before they could even think about it. That limited their ability to come up with new ideas'.
'A white page can seem intimidating because the participants might feel that they need to fill the whole page'.
'We were asked as participants to do several short and intense work tasks. That produced a lot of ideas, but a lot of the new solutions did not solve the problem because it was not clear what the workshop facilitators asked for'.
'It was very challenging to get the workshop participants to write down or draw instead of only talking'.

Preparing for the workshop:
'Preparing for the workshop forced us to discuss our findings with each other before presenting them to the rest of the team'.
'We should have done a dry-test of our workshop beforehand.…We interrupted each other often during our presentation of the findings'.
'I was not exactly sure what to ask the workshop participants to do because I was not sure what I wanted to get out of the workshop'.
'Next time I would like to be better at tapping into the competence of the workshop participants, get them to prepare themselves for the workshop, check what they think would be most useful for them'.

These extracts show that the students become immediately aware of important distinctions that can really improve the quality of their workshops, for instance, testing the workshop plan beforehand, designing a way to communicate results, designing activities to engage the team, and dealing with the ownership of ideas.

Screenshots extracted from the video documentation of the workshop showed some skills that the students have been able to use during this learning activity (see Figures 7–9 below).

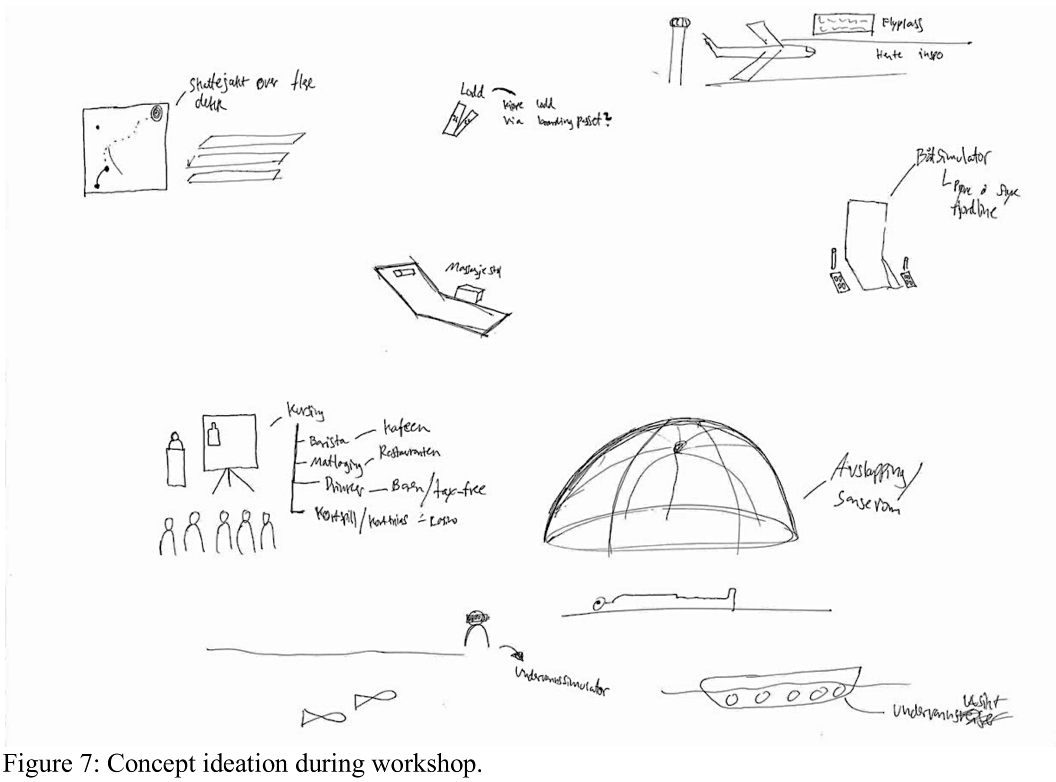

Figure 7: Concept ideation during workshop.

Figure 8: Results presentation and co-design in workshop. Pictures from the field study are presented on a screen, a reconstructed map of the studied area is put forward on the table, and the students use sketching while talking.

Figure 9: Results presentation and co-design in workshop. A map of the main observed issues is put forward on the table. Post-its and a white board are used to visualize and analyse short ideation tasks given to the participants.

4. DISCUSSION

Overall, the course seemed to be very useful for the students. One student wrote in the field study self-evaluation: 'It's been very educational to observe a context and users in their context, compared to what I have done previously, which was mostly interviews of users outside their context'.

This course had several limitations. First, it is especially useful to industrial design students who are already trained in human-centred design activities such as collecting insights from user behaviours. It would be interesting to test the course with engineering design students and maritime engineers working with the design of products and services in the maritime industry. They might have a perspective that is more technology-centred than human-centred. To explore this topic, we plan to build on research

of the introduction of human-centred design and human-factors concepts in technology-centred maritime design processes. Lutzhoft and Abeysiriwardhane as well as Salustri and Neuman look at the problem from an education perspective, while Lundh and Mallam look at it from an operational perspective (Abeysiriwardhane et al., 2015, 2017; Mallam et al., 2015; Mallam and Lundh, 2014; Salustri and Neumann, 2017).
Second, the course requires the organisation of a field study on a ship. Without the opportunity to carry out an actual field study, the course loses most of its essence. However, it is possible to find alternatives to field study on a ship. This year one student had to be excused and did his field study in a café while traveling. However, we recommend finding study sites that are able to accommodate an entire class to make it possible for teachers to be present in the near vicinity throughout the study.

The feedback given by the ship company that hosted the field study was positive. First, the management of the company has reviewed the observations, analyses and design proposals produced by the students in their reports and found it pertinent and useful. Second, the ship's crew was pleased with the experience and there was no hindering of their work or of the ship operations.

For further development of the course, we are interested in exploring the following directions:

- a course that can be done partially online, allowing the students to design and execute their own field study
- an online-based test of observation skills: photos from previous field studies are shared online and the students are asked to make observations so that we can compare what we have observed with what the students manage to pick-up
- an internal course tailor-made for a company and its own design processes

5. CONCLUSION

From our evaluation, the course seemed to be successful in assisting students in learning a process and techniques to plan and execute a field study. We believe this is a useful contribution to making design education for human-centred design processes available to the maritime industries. This is important because it can affect the safety and efficiency of operations and improve future maritime innovation processes.

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ERRATA SHEET

Section /Figure	Page	Original text	Corrected text
1.7	10	A summary of my research findings and a presentation of the contributions of my research (**Chapter 4** – Research findings	A summary of my research findings and a presentation of the contributions of my research (**Chapter 4** – Research findings
1.7	10	The four publications are included in **Chapter 0** after the references (Chapter 8).	The four publications are included after the references (Chapter 8).
2.2.1	17	Furthermore, I refer to the "ship operation" as the use of the ship by its human operators, either an actual **use of possible** future use.	Furthermore, I refer to the "ship operation" as the use of the ship by its human operators, either an actual **use, or a possible** future use.
2.2.1	18	In the 2009 IMDC State of the Art Report on Design Methodology, Andrews et al. (**Andrews et al.,** 2009)	In the 2009 IMDC State of the Art Report on Design Methodology, Andrews et al. (2009)
2.2.1	19	They noted some similarities between the systems engineering approach and **his** model	They noted some similarities between the systems engineering approach and **Andrews´** model
2.3	22	an example of a management tool under the category of "project management issues" in a model presented by Andrews (1998, fig. 8 p.209**)**).	an example of a management tool**,** under the category of "project management issues"**,** in a model presented by Andrews (1998, fig. 8 p.209).
2.3.1	23	they cannot invoice this work until a contract is signed the ship owner	they cannot invoice this work until a contract is signed **with** the ship owner
2.3.2	23	the IMO regulations for **ship bridges and ship engine rooms**, respectively.	the IMO regulations for **ship engine rooms and ship bridges**, respectively.
2.3.2	24	the bridge layout and design may not permit safe resource management" (Sørensen **& Lützhöft**, 2018, p. 1).	the bridge layout and design may not permit safe resource management" (Sørensen**, Lützhöft, & Earthy**, 2018, p. 1).
2.3.4	25	this list is not intended to be exhaustive list and does not refer **to ,**	this list is not intended to be exhaustive list and does not refer **to,**
3.3.3	45	The cases that I studied were **instrumental**	The cases that I studied were **"instrumental"**

3.4.1	48	This case is based on **field study** #1.	This case is based on **Field Study** #1.
Figure 13	49	Figure 36: **Example of early mapping of the field study process.**	Figure 37: **Early example of field study process mapping. Deliverables are represented with symbols, and their location indicates who is supposed to produce them, and when.**
Figure 14	50	Figure 38: Analysis of an early version of the integration model by placing data on concept categories (the data is intentionally not readable for confidentiality reasons).	Figure 39: Analysis of an early version of the integration model by placing data on concept categories (the data is intentionally not readable for confidentiality reasons). **The three circles represent a Venn diagram: Ship design process (Yellow), Ship operation (Green), Ship architecture (Blue).**
3.4.2	50	an approach similar to what some authors refer to as **bricolage**	an approach similar to what some authors refer to as **"bricolage"**
3.4.2	51	in order to plan **field study** #1	in order to plan **Field Study** #1
3.4.2	54	Then I could benefit from their **own ideas of how to visualise the same idea as well as from their explanations of the idea.**	Then I could benefit from their **reflections about the ideas conveyed in my sketches, and reflect upon how they proposed to visualise my ideas.**
Figure 20	59	Figure 40: The design process reported in the publication.	Figure 41: The design process reported in the publication. **This figure also shows how the early process mapping (represented in Figure 13) has evolved.**
4.3	63	Gernez, E., & Nordby, K. (in press). Implementing Field Research in Ship Design. **Transactions of the Royal Institution of Naval Architects, 158**(C1).	Gernez, E., & Nordby, K. (in press-**b**). Implementing Field Research in Ship Design. ***Transactions of the Royal Institution of Naval Architects, 158***(C1).
4.3	64	(Nordby et al., in press; Schaathun et al., unpublished manuscript**,** 2017).	(Nordby et al., in press; Schaathun et al., unpublished manuscript**; Schaathun, Tran, Tollefsen, & Gernez,** 2017).
4.4	64	Gernez, E., & Nordby, K. (in press). A 10-day Course to Plan and Execute Field Studies for Maritime Design Processes. **Transactions of the Royal Institution of Naval Architects, 158**(C1).	Gernez, E., & Nordby, K. (in press-**a**). A 10-day Course to Plan and Execute Field Studies for Maritime Design Processes. ***Transactions of the Royal Institution of Naval Architects, 158***(C1).
Figure 25	70	Figure 42: Design activities in the proposed process.	Figure 43: Design activities in the proposed process. **OPAR is built to be used at any time during the process.**
5.1.3	71	**As shift**, a shift in focus towards end-users' experiences took place in two steps.	**As such**, a shift in focus towards end-users' experiences took place in two steps.

Figure 27	75	Figure 27: **Different uses of the OPAR framework lead to different design processes.**	Figure 27: **OPAR is built to fit with different types of design processes. Technology-centred process will navigate mainly in the architecture part; human-centred processes will navigate in both architecture and operation parts.**
5.2.3	76	to create new design methods that help generate connections across framework.	to create new design methods that help generate connections across **the** framework.
5.2.4	77	so that the created scenarios re-enacted and modified	so that the created scenarios **could be** re-enacted and modified
Figure 28	77	Figure 44: **E**nacting service interventions on an engine with a mechanic, using props to represent engine parts.	Figure 45: **Prototyping session after Field Study #1: Re-e**nacting service interventions on an engine with a mechanic, using props to represent engine parts.
5.3	79	between the design process steps related to the **preliminary** design of a ship, and the operation of a ship after its construction;	between the design process steps related to the **concept** design of a ship, and the operation of a ship after its construction;
Figure 30	82	Figure 46: Lurås and Nordby´s model of design-driven field research is one example of design activity **example** in OPAR.	Figure 47: Lurås and Nordby´s model of design-driven field research is one example of design activity in OPAR.
5.3.4	82	As another example, we used a prototyping technique in **field study** #1	As another example, we used a prototyping technique in **Field Study** #1
5.3.5	85	The concept of a 3D CAD model that contains information about operational scenario (Figure 32) is an**other** example of **a** hybrid representation **that I worked with**.	The concept of a 3D CAD model that contains information about operational scenario**s** (Figure 32) is an example of hybrid representation.
5.3.5	85	Conversely, the process that led to the creation of this concept	Conversely, the **actual design** process that led to the creation of this concept
Figure 35	86	Figure 48: The connections generated **by field studies:**	Figure 49: The connections generated **when field studies are carried out inside OPAR:**
5.3.5	87	between design process steps: **preliminary** design and ship in operation	between design process steps: **concept** design and ship in operation
5.4	87	field studies contribute to generate connections between **design onshore and offshore** design activities	field studies contribute to generate connections between **at sea and ashore** design activities
6.3	91	For instance, a description of the systems the end-users use when they perform work task is important	For instance, a description of the systems the end-users use when they perform work task**s** is important

6.4	92	DNVGL has also carried their own field studies after Field **s**tudy #2	DNVGL has also carried their own field studies after Field **S**tudy #2
7.2	96	they get access to information about the usability of the ship systems and **whether, how or** to what extent the designed ship systems (or ship architecture) match**es** the end-users' needs	they get access to information about the usability of the ship systems and to what extent the designed ship systems (or ship architecture) match the end-users' needs
7.3	97	The OPAR framework, which thus frames the design work of human-centred, collaborative, field-driven ship design processes, is also **suited** to support design cases**,** such as the retrofitting of new systems on older ships	The OPAR framework, which thus frames the design work of human-centred, collaborative, field-driven ship design processes, is also **built** to support design cases such as the retrofitting of new systems on older ships
7.4	97	To help them in this process, the OPAR framework combines design activities that focus on the analysis of operational experiences, and design activities that transfer the result**S** of such analysis	To help them in this process, the OPAR framework combines design activities that focus on the analysis of operational experiences, and design activities that transfer the result**s** of such analysis
8	99	Abeysiriwardhane, A. (2014). Human factors for ship design; Exploring the bottom rung. **Transactions of The Royal Institution of Naval Architects, 156**(C1), 153–162.	Abeysiriwardhane, A. (2014). Human factors for ship design; Exploring the bottom rung. ***Transactions of The Royal Institution of Naval Architects, 156***(C1), 153–162.
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		Ecologies, 7-10th June 2015, Stockholm, Sweden.	
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8	112	Schaathun, H. G., Tran, Q., Tollefsen, M., & Gernez, E. (2017). ***Data and knowledge management in field studies; A case for semantic technologies.***	Schaathun, H. G., Tran, Q., Tollefsen, M., & Gernez, E. (2017). **Data and knowledge management in field studies; A case for semantic technologies.**
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8	114	Vimatec. (2018). ***Gerneral arrangement drawing***.	Vimatec. (2018). **General arrangement drawing.**