THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

# Human Centred Design for Maritime Safety:

## A User Perspective on the Benefits and Success Factors of User Participation in the Design of Ships and Ship Systems

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Gothenburg, Sweden 2016

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Technical report no 16:162
ISSN 1652-9189

Published and distributed by:

Department of Shipping and Marine Technology
Division of Maritime Human Factors and Navigation
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Printed by:

Reproservice at Chalmers University of Technology
Gothenburg, Sweden 2016

# Abstract

For over six decades, Human Centred Design (HCD) has been considered a desired design approach for the implementation of Human Factors/Ergonomics (HF/E) knowledge and methods for understanding the needs of the end-users. Although other comparable frameworks exist, they can be seen as subcategories or as tools for HCD, as HCD is considered by some as an overarching approach. This design approach has gradually been integrated into different fields, but engineering sciences have been more reluctant towards embracing its adoption. Although these challenges may be explicable – one of them being that HF/E methods are often not immediately understood and applicable in industrial settings – the maritime sector has begun to overcome these challenges and to understand and highlight the impact of the human element on the safety and efficiency of maritime operations and environmental protection. Nevertheless, more initiative and attention to HF/E is needed. Thus, the work considered in this thesis takes a proactive approach towards the integration of HCD in the maritime domain by involving maritime end-users in a discussion about the opportunities of human-centred and participatory design. This was done through two focus group interviews with two different participant samples of end-users, with special focus on the navigation of merchant vessels. The analysis of the focus group interviews was guided by a Grounded Theory approach. The work presented in this thesis is part of the project *Crew-Centered Design and Operation of Ships and Ship Systems* (CyClaDes), supported by funds from the European Commission and its Seventh Framework Programme. The CyClaDes project intended to promote the increased potential impact of HF/E and HCD knowledge on ship design and operations, by understanding where and how to best integrate it and where and how barriers to its integration occur. The findings in this thesis highlight HCD and its participatory principle as a means to attain a set of benefits at a physical, cognitive, psychosocial, organizational, and socio-political levels, and ultimately attain safer maritime operations. The results suggest that successful integration of a human-centred and participatory design philosophy in the maritime domain should include more and appropriate user representativeness within design, rule-making and purchasing to bridge the gap between the requirements of the users and of other stakeholders, between design and usability. The benefits of, and the prerequisites for, successful HCD integration within the complex sociotechnical system of shipping describe a holistic model for maritime HCD.



**Keywords:** user centred design; participatory ergonomics; participatory design; co-design; design decisions; domain knowledge; sociotechnical systems; integration; maritime safety.

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# Acknowledgements

First, I would like to acknowledge the funding body that supported the work in this thesis, conducted within the Crew-Centered Design and Operation of Ships and Ship Systems (CyClaDes) project from the European Commission and its Seventh Framework Programme [Grant agreement no.: 313972, www.cyclades-project.eu]. I would like to thank my main supervisor Dr. Scott MacKinnon, co-supervisor Dr. Joakim Dahlman, and direct manager Dr. Monica Lundh for their guidance. I would also like to thank my former supervisors Dr. Margareta Lützhöft, Dr. Margareta Ljung and Dr. Thomas Porathe, and my Human Factors and Saga colleagues for the support, inspiration and fellowship. A special thank you to Linda de Vries, Dr. Per Hogström, Dr. Eric Holder, the PPU colleagues, Dr. Barbara Czarniawska, and Dr. Richard Torkar. Last but not least, thank you Hedy, Francesco, Neto, Nina, Nicolas, Suvi, Edna, Jeff, Aljoscha, Vanesa, and Fatemeh for making me feel more at home; Arvid, för att du är min 'ljusstråle' och nirvana per diem. Mãe, pai, Gu, nada disto importa sem vocês.

# List of Appended Articles

This thesis is based on the research from the following articles:

**Article I** Costa, N., & Lützhöft, M. (2014). *The values of ergonomics in ship design and operation*. Paper presented at the International Conference on Human Factors in Ship Design & Operation, 26-27 February 2014, London, UK.

*Non-peer-reviewed conference paper*

**Article II** Costa, N., de Vries, L., Dahlman, J., & MacKinnon, S. (2015). Perceived success factors of participatory ergonomics in ship design. *Occupational Ergonomics, 12*(4).

*Peer-reviewed, accepted and published scientific journal article*

**Article III** Costa, N., de Vries, L., & Dobbins, T. (2015). Introduction to human-centred design for naval architects and designers. In T. N. Institute (Ed.), *Improving ship operational design* ($2^{nd}$ ed., pp. 3-16). UK: The Nautical Institute.

*Internally peer-reviewed by EU project partners, accepted and published book chapter*

Nicole Costa is the first and main author of all appended articles, developed with the support of the co-authors through a series of iterations.

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# List of Abbreviations

| | |
|---|---|
| **AB** | Able Seamen |
| **ACD** | Activity Centred Design |
| **CCD** | Crew Centred Design |
| **COLREGs** | International Regulations for Preventing Collisions at Sea |
| **CyClaDes** | Crew-Centered Design and Operation of Ships and Ship Systems |
| **EPA** | European Productivity Agency |
| **HCD** | Human Centred design |
| **HF/E** | Human Factors and Ergonomics |
| **ICS** | International Chamber of Shipping |
| **IEA** | International Ergonomics Association |
| **IMO** | International Maritime Organization |
| **ISM** | International Safety Management |
| **ISO** | International Organization for Standardization |
| **MARPOL** | Prevention of Pollution from Ships |
| **SAR** | Maritime Search and Rescue |
| **SOLAS** | International Convention for the Safety of Life at Sea |
| **STCW Manila** | Standards of Training, Certification and Watchkeeping for Seafarers |
| **UCD** | User Centred Design |
| **UX** | User Experience |

# 1 Introduction

Over the past sixty years, designers and manufacturers have been increasingly engaging end-users of their products and designing these products on the basis of users' expected tasks, existing problems, and needs (Sanders & Stappers, 2008). Human Centred Design (HCD) is an example of a design approach that resulted from and influenced this development having spread to industrial and interaction design in the 1990's (Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011). Still today, HCD is one of the three main design movements that govern the realm of design and the one to put the human first (Giacomin, 2014). The International Organization for Standardization (ISO) and the International Ergonomics Association (IEA) have designated HCD as the endorsed approach for the integration of human factors and ergonomics (HF/E) and usability principles, knowledge, and techniques in design practice. HCD is described as a multidisciplinary design approach based on an iterative design and evaluation process, and on the contribution of key stakeholders such as the end-users to improve the understanding of user and task requirements (ISO, 2010; Maguire, 2001; Mao, Vredenburg, Smith, & Carey, 2005). By implementing this approach, products, systems and services should be made more "*usable and useful by focusing on the users, their needs and requirements*" (ISO, 2010), consequently optimizing "*human well-being and overall system performance*" (IEA, 2016). Achieving this in the maritime transport services is necessary, since the shipping industry is related to approximately 90% of the world trade today, hence being at the forefront of global economy (ICS, 2015) and having a decisive impact on international sustainable development. The proliferation of automation resources and decrease in crew numbers also represents a need for more training and skill development, better human-technology interaction and function allocation, and more HF/E integration in ship design and operations (Grech, Horberry, & Koester, 2008; Praetorius et al., 2015).

The integration of HF/E in design processes remains generally limited in engineering (Norros, 2014; Vicente, 2006) and facilities and systems continue to be designed with little consideration for the humans who interact with them (Edwards & Jensen, 2014). Although "*the fields of human factors/ergonomics and design have a common aim – to develop products and systems that successfully meet the needs of their users*" (Langford & McDonagh, 2003, p.1), researchers have systematically found that this view is not easily implemented and maintained in the engineering world due to challenges in making scientific human factors methods design-driven (Norros, 2014) and to adjusting them to industrial use (Andersson, Bligård, Osvalder, Rissanen, & Tripathi, 2011; Norros, 2014). In the maritime domain, design work has been mainly executed by engineers who tend to focus on technical aspects of design more than on the end-users (Lurås, 2016; Petersen, 2012), which has made it difficult conveying an HCD and usability mind-set (Petersen, 2012) and hence the practice of human-centred and participatory approaches. The lifespan of modern ships, which is usually between twenty-five and thirty years (although it can reach fifty or more), and the rapid technological advancements also diminish the opportunities for HF/E interventions and standardization (Grech et al., 2008). Thus, onboard work environments and equipment remain insufficiently capable of supporting the users (Lurås, 2016). Although there has been extensive focus on safety and major improvements to maritime occupational health and safety, maritime casualties continue to occur (CyClaDes, 2015a; Earthy & Sherwood Jones, 2010; Kataria, Praetorius, Schröder-Hinrichs, & Baldauf, 2015; Lurås, 2016) and occupational mortality and morbidity rates for seafarers remain among the highest of all occupations in western society (Roberts, 2008; Roberts & Marlow, 2005). Although concrete statistics that support the conclusions that the root causes of maritime casualties are related to human factors issues are limited, 'human error' is still reported the most prominent reason (Lurås, 2016; Lützhöft, Grech, & Porathe, 2011), implicated in between 75-96% of the accidents (Hanzu-Pazara, Barsan, Arsenie, Chiotoroiu, & Raicu, 2008; Veysey, 2013). Concurrently, approximately one third of all marine accidents have also been associated with poor design (Grech et al., 2008), which further draws attention to the need for HF/E integration in the sector.

## 1.1 Research Scope and Aim

This thesis aims to take a step into filling the HF/E gap in the maritime domain by incentivizing improved design. This is done through discussing the role and potential of HCD, particularly from the standpoint of the end-users (seafarers). This work was conducted within the *Crew-Centered Design and Operation of Ships and Ship Systems* (CyClaDes) project, supported by funds from the European Commission and its Seventh Framework Programme. The purpose of the CyClaDes project was to promote the increased potential impact of HF/E and HCD knowledge across the design and operational lifecycle of ships and ship systems to improve maritime safety, efficiency and system performance. This was intended by instigating communication between designers, end-users, ship-owners and authorities and by focusing on where and how barriers to HF/E and HCD integration occur; and where and how to best integrate it (CyClaDes, 2015b). This thesis investigates end-user perceptions on the benefits of and success factors for human-centred and participatory approaches to design in the maritime domain.

### 1.1.1 Research Questions

This thesis is based on the following research questions:

[1] What are the benefits (output) that result from a human-centred, participatory approach to the design of ships and ship systems and equipment?

[2] What are the success factors (input) for involving the end-users and achieving said benefits?

[3] How can said success factors be accommodated and HCD be integrated in the maritime domain in order to achieve the benefits?

### 1.1.2 Appended Articles

In accordance with the aim and research questions of this thesis, the following articles have been appended:

**Article I** This article investigated the perceptions of end-users of the maritime sector concerning the benefits of the HCD approach and of user involvement in design. The analysis of two focus group sessions was performed and the commonalities between them were scrutinized and transformed into categories and then linked to HF/E dimensions of ship design found in literature.

**Article II** This article provided a deeper analysis of the second focus group presented in Article I. The focus group collected the opinions of young trainees, students of a Master Mariner programme, about end-user participation in marine design processes, and resulted in a conditional/consequential matrix of success factors and benefits.

**Article III** This was published in the form of an introductory and practical book chapter with the aim of introducing HCD to students and professionals of naval architecture and ship systems design as a way to help integrate HF/E in marine design practice.

### 1.1.3 Delimitations

The conclusions drawn from this research pertain mainly to marine structures and systems of merchant vessels. Although the content may be applied across other vessel types or even other sectors, it was not the focus of this thesis nor of the appended articles.

The Human Element laid out by the International Maritime Organization (IMO) is of relevance in this thesis due to its global impact in the maritime domain. The HCD model and principles issued by the ISO are especially considered, bearing in mind the ISO's influence over general design practice, although other HCD models exist (e.g., IDEO.org, 2015; LUMA Institute, 2012). It must be noted, however, that one of the main arguments of this thesis is that, regardless of the HCD model adopted, HCD must be contextualized for the maritime domain and specific projects to be successfully applied.

# 2 Theoretical Background

## 2.1 Human Factors and Ergonomics

*Ergonomics*, from the Greek *ergo* (work) and *nomos* (natural laws), can be defined as the applied science of work, and its foundations date back to Ancient Greece or even the Stone Age with the making of tools. However, the name itself was only introduced in 1857 by the Polish scientist Wojciech B. Jastrzębowski (Jastrzębowski, 1857, reprinted in 2006) and later coined by the British chemist and psychologist Kennet Frank Hywel Murrell in his military studies during and post-World War II (Chartered Institute of Ergonomics & Human Factors, 2016).

Ergonomics started to be associated with the study of human physical attributes in industrial contexts for the design of workstations and work processes in Europe during the 1950s. It was in North America that the terms *human factors* and *human factors engineering* originated and these applied the same methods as ergonomics but not necessarily to work settings (e.g., military settings or technology for personal use) (Helander, 1997; Koskinen et al., 2011). Human factors, human factors engineering and engineering psychology developed from the study of systems performance in military settings (Helander, 1997). Human factors was understood in its wider spectrum of physical, cognitive, psychological and social properties of humans in relation to a sociotechnical system (Chartered Institute of Ergonomics & Human Factors, 2016; Koskinen et al., 2011).

The European Productivity Agency (EPA) established a Human Factors Section in 1955, which led to an international association of work scientists in 1957, which, in turn, formalized the IEA. The initial focus of this association was on the wellbeing and productivity of the workers from a biological standpoint, but this soon expanded towards a focus on cognition and on non-vocational activities due to the advancement of technology (Helander, 1997). Despite the initial differentiation, ergonomics and human factors are today treated equally and have merged into the same discipline. The IEA provides the following definition:

> *"Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."*
>
> IEA (2016)

HF/E as an applied scientific discipline adopts a multidisciplinary and sociotechnical systems perspective, considering the various elements of a work system and their interactions. This involves the study of human capabilities, limitations and needs, taking into consideration the physical, cognitive, social, organizational, contextual and environmental aspects of work, in order to fit the task and tools to the human. The domains of specialization within HF/E that represent human competencies are:

- Physical ergonomics refers to anthropometrical, anatomical, physiological and biomechanical characteristics of the human body related to human activity. This can consist of work-related musculoskeletal disorders, working postures, manual handling, repetitive movements, workplace layout, product design, safety and health, noise, lighting, motion, vibrations, temperature and hazardous materials. These aspects can not only affect physical well-being and mental health, but also influence overall human performance (IEA, 2016).

- Cognitive ergonomics is related to mental processes such as perception, interpretation of information, and motor response. This branch of ergonomics involves competencies such as the design of activities, systems and technology that can fit the human mind and cognitive abilities; mental workload and performance; stress; and decision-making support (IEA, 2016).

- Organizational ergonomics focuses on the organizational context and the optimization of sociotechnical systems, including the organizational structures, policies, cultures and processes for communication and decision-making on who holds which skills and knowledge, who has done and will do what, as well as other features of the human capital and intellectual property. On this level, the focus can range from communication to human resource management, knowledge management, teamwork, arrangement of work schedules, participatory ergonomics/design, cooperative work, organizational culture, and quality management (IEA, 2016).

## 2.2 A Sociotechnical Systems Approach

Reductionism has been a common heuristic in the way humans problematize things, but not always considered the best approach if we wish to design technology fit for people, especially in complex sociotechnical systems like the maritime industry (Lützhöft et al., 2011). Putting too much reliance into the capabilities of human beings or into the functions of technology alone has resulted in detrimental effects. Taking a holistic approach can capture not only the attributes of the different elements but also of their relationships and emergent properties (Lurås, 2016; Vicente, 2006), which are not physically palpable but have an immense influence over the functioning of the system.

Sociotechnical systems are systems of a complex nature within which there are socio-political and technological elements and wherein these elements interact and should be oriented towards a common goal. *Systems thinking* is promoted as the path to address the division between humanistic and mechanistic sciences and the subsequent technology-driven design trend that fails to answer the needs of the people who are meant to use it (Vicente, 2006). The issue of having unseemly fitted designs to the reality of work tasks occurs when there is an equally unseemly design mind-set. The more humans evolve, the more we use machines to complement naturalistic thinking. Nonetheless, we still study them separately as two elements of a system that may interact but that share nothing else in common. Contrarily, it has been suggested that machines should be treated as an intrinsic part of our society, making the social and the technical inseparable:

> *"I have sought to show technicians that they cannot even conceive of a technological object without taking into account the mass of human beings with all their passions and politics and pitiful calculations, and that by becoming good sociologists and good humanists they can become better engineers and better-informed decisionmakers. An object that is merely technological is a utopia (…) Finally, I have sought to show researchers in the social sciences that sociology is not the science of human beings alone – that it can welcome crowds of nonhumans with open arms (…)"*
>
> Latour (1996, p.viii)

Indeed, studying technology and humans separately seems counterproductive when technology does not exist without humans nor do humans live isolated from technology. According to Vicente (2006), knowledge about people can be organized into different levels: the physical, the psychological, the team, the organizational and the political. The *physical* level corresponds to the physical capabilities and limitations shared by the majority of the intended users of a particular design, regarding body shape, physiology, strength, and movement. The *psychological* refers to the cognitive characteristics, such as short- and long-term memory capacity, logic and expectations, as well as our cognitive limitations. Taking into account that certain products are to serve a *team* of two or more people working together towards common goals, communication, coordination, efficiency and effectiveness are aspects that must be thought of when designing, as well as the limitations of working in teams. Teams are usually working within an *organization*, whose leadership, information flow, reward system, organizational behaviour and blame culture can impact performance. Staffing and work schedules are included in this level. The *political* is the top level that comprises every design. Designers must consider the socio-political and cultural status of things in order to create designs that can survive and prosper in the marketplace (Vicente, 2006).

Similarly, an alternative sociotechnical systems model, "The Septigon Model", has been found to be consistent with the organizations in the maritime domain (Grech et al., 2008). This model considers the physical, metaphysical and technological elements of a system as a single unit, the interactions among them and how they influence system performance for the achievement of a common goal. These elements comprise the individual, the technology, the practice, the group, the physical and organizational environments, and society and culture. The *individual* refers to the human element in the system and its physical, sensory and psychological limitations. *Group* refers to communication, team management and regulatory activity aspects. *Technology* is associated with machines (hardware and software), tools, manuals and signs. *Practice* refers to informal rules and customs, unlike *organizational environment*, which is related to formal rules, official procedures, instructions, norms, policies, and organizational culture. The *physical environment* regards weather, visibility conditions, temperature, lighting, noise, vibration, motion, space and display. Finally, *society* represents the socio-political, economic and cultural environment that surrounds the organization, in its broad spectrum.

The systemic way of viewing problems and their solutions opposes the more reductionist outlook that, despite yielding abundant knowledge, has led to the harmful separation of the engineering and the humanistic sciences, which does not allow for an understanding of the bigger picture (Forsman, 2015; Vicente, 2006) and is likely less useful for preventing system errors (Grech et al., 2008).

## 2.3 Participatory Approaches to Design

Besides the holistic perspective, user participation is an intrinsic trait of the HF/E discipline (Langford, Wilson, & Haines, 2003), as much of the HF/E practice has unavoidably been participative to some extent (Haines, Wilson, Vink, & Koningsveld, 2002). Research on the concept of user participation dates back to the 1970s, when in Scandinavia the Collective Resource Approach was founded to heighten the value of industrial production by involving workers in the design and development of new work systems (Gill, 1996; Kraft & Bansler, 1992; Sanders & Stappers, 2008), and in the democratization of computer automation (Steen, 2011). Other European programmes like the German humanization of work (Kissler & Sattel, 1982) and the British Lucas Plan of socially useful production and technology (Smith, 2014) were also important players in the shift to participatory approaches (Gill, 1996). In the early 1980s, discussion around the concept of user participation shot up in the HF/E community (Langford et al., 2003).

User participation can be disguised under different names: participatory design (Barcellini, Prost, & Cerf, 2015; Langford et al., 2003), participatory ergonomics (Haines et al., 2002; Vink, Koningsveld, &

Molenbroek, 2006), HCD (or UCD)[1] (ISO, 2010; Langford et al., 2003), or co-design (Sanders & Stappers, 2008). Even though they might differ in their origins and nature, they hold principles in common (Steen, 2011) and engage people in the planning and controlling of the design of their own work and leisure activities and tools.

Participatory approaches to design establish a collaborative framework within an HF/E intervention process that organizes relevant users and stakeholder groups affected by the change. The idea is that discussions amongst stakeholders who do not necessarily have skills or expertise in design or HF/E can stimulate the identification and codification of pertinent tacit knowledge related to the process. These could include, but are not limited to, identifying aspects of their workplace, systems or tools that can be improved, developing solutions for problems according to their knowledge and experience, and supporting the development of such solutions (Glina, Cardoso, Isosaki, & Rocha, 2011). Involving users in design can improve the transmission of relevant information and knowledge within and between organizations. In fact, the more complex the problem-solving, the more the actors in the network should engage in the knowledge transfer process to fulfil the capacities required (generative, disseminative, absorptive, and adaptive/responsive) to successfully solve the problem (Parent, Roy, & St-Jacques, 2007). Involving users can enhance the meaningfulness of work (Glina et al., 2011); optimize performance; attenuate work-related health issues (Glina et al., 2011; Österman, Berlin, & Bligård, 2011); increase learning within the organization, comfort and productivity (Vink et al., 2006; Österman et al., 2011); improve design ideas and solutions, and facilitate implementation (Haines et al., 2002).

User involvement can take different forms in terms of direct or indirect (via representatives) participation; where in the design process the users are involved; among other dimensions of participation (Haines et al., 2002; Langford et al., 2003). Users can also be involved in a passive fashion by being given directed tasks or asked to comment on design concepts developed by others. The current participatory design and HCD wave, though, calls for active user involvement at the early design stages, meaning that users can, collectively with designers and other stakeholder groups, influence design ideation and conceptualization (Sanders & Stappers, 2008). Active user involvement can increase the acceptance and commitment of the users to the new product as they understand that the design is being suited to them rather than enforced (Maguire, 2001), and produce a sense of control and ownership, on the assumption that the users later experience the things they helped develop or improve upon (Bligård, Österman, & Berlin, 2014; Glina et al., 2011; Österman et al., 2011).

The use of participatory approaches by practitioners, however, is still limited (Olsson, 2004). Empirical usability evaluations in which users interact with the product under development by being asked to perform certain tasks, for example, are reported to imply higher costs and time-span than analytical usability evaluations (e.g., heuristic) which don't require users as test subjects (Bligård & Osvalder, 2013). The latter are more commonly used and do not allow space for active user participation (Olsson, 2004). The inertia of practicing participatory approaches can also be explained by the lack of a clear definition of the concept and process of participation, especially since different participatory approaches exist and differ somewhat in their definitions and/or contents. Properly defining a user population or fulfilling the needs of all different types of users of one sole system may also represent a challenge for designers (Olsson, 2004). Participatory approaches can also cause uncertainty due to communication gaps and lack of consensus between stakeholders (Mallam, 2014). Studies have

[1] Human Centred Design (HCD) and User Centred Design (UCD) are terms used interchangeably today. For this thesis, however, the adopted term is HCD so as to regard for users as well as for other stakeholders affected by design practice (ISO, 2010), as well as for broadening and humanizing the concept of user (Steen, 2011). The term UCD will, thus, be used solely in the historical sense of the design movement.

indicated that designers and engineers may experience some difficulty in assimilating input from users into their design process. Users may not be able to adapt their needs and communication patterns towards what designers need to know and can manipulate (Bligård et al., 2014). This requires the use of a common language and support from the management team (Mallam, 2014), as well as the inclusion of multidisciplinary skills on the design team and the maximization of direct interaction between designers and end-users (ISO, 2010). Gathering representative user groups from the maritime domain to participate in ship and ship systems design or refitting may also be a logistically challenging endeavour due to the nature of their jobs at sea (Österman et al., 2011). Lurås (2016) identified that accessing users and field sites as one of the main challenges that designers face when designing in and for complex contexts. The author suggested, however, how this problem could be improved by adopting systems thinking and HCD, and by initially following users and gaining knowledge about contexts of use through online platforms as preparation for fieldwork.

Active user participation is incentivized, as it is considered a basic principle in participatory approaches (Gulliksen et al., 2003; ISO, 2010; Olsson, 2004). The communication between designers and end-users is positively related to the outcome of the design and a mutual understanding allows for a safer, more efficient ship design and successful operation, as well as it decreases the time and resources spent on problem-solving, design correction and maintenance, and in turn diminishes the exposure of the seafarers to the perils of poor design and implementation (Österman, 2012). Employee participation can elevate crew morale and make the crew feel heard; it can improve business operations and influence purchasing processes. Considering this, Österman, Rose, and Osvalder (2010) propose that employee participation should become part of every organizational culture. It can also facilitate more rapid technological and organizational changes, a higher commitment to agreed-upon solutions and a sense of empowerment in the participants from witnessing the complex decisions that surround a design process (Österman et al., 2011) (see also Vink et al., 2006). Involving operational experts in design practice is the essence of HCD and the key to achieving harmonious interactions (Petersen, 2012).

## 2.4 Human Centred Design

Society underwent major changes in the 1960s, a period of recovery after World War II. The societal, political, economic, cultural and technological changes represented an opportunity for design fields like graphic, industrial, interaction, service and community design, as well as design management and design research to propagate and diversify. Before this shift, design in the 1950s and early 60s was mainly governed by a rationalistic view, followed by operations research and systems theory, and the design methods movement (Lurås, 2016). This movement was, however, criticized as insufficient in accounting for the human, social, and artistic facets of design, as well as in solving imminent ecological issues that were starting to garner society's attention at the time. The integration of ethnography, behavioural and social psychology into the design process began to play an increasingly important role in design practice and in mitigating the preceding mechanistic paradigm. This turned design into an emergent scientific field of study, and apprenticeship into academic skill development (Koskinen et al., 2011). For this reason, the tacit knowledge of design practitioners had to be captured and articulated through design research (Koskinen et al., 2011). This design shift served as a catapult to the User Centred Design (UCD) movement.

UCD developed from a combination of Usability Engineering, Human-Computer Interaction (Williams, 2009), as well as the previously described emphasis on design ergonomics and participatory approaches in the 1970s. UCD firstly became prevalent in computer science and artificial intelligence (Giacomin, 2014; Koskinen et al., 2011), but in the 1990s it also became rampant within industrial and interaction design, and was popularized by the famous Silicon Valley design company IDEO (Koskinen et al., 2011). More recently, the term HCD rather than UCD has been made official by the ISO 9241-210:2010 to advocate the involvement of all stakeholder groups affected by the design, including end-users.

HCD can be illustrated as *"an emancipatory tradition which places human needs, purpose, skill, creativity, and human potential at the centre of activities of human organisations and the design of technological systems. It has broader concerns in the areas of scientific traditions, culture and technology, industrial cultures, technology transfer and development, globalisation, sustainability, and technology assessment"* (Gill, 1996, p.1). As per the ISO 9241-210:2010, an "*approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques*". Making a product "more usable" is about improving usability and this 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). But besides enhancing effectiveness, efficiency and satisfaction, other social and economic benefits for the stakeholders can be achieved through HCD (Maguire, 2001). For example, human well-being, accessibility and sustainability can be improved, reducing discomfort, stress, propensity for errors (Maguire, 2001), and neutralizing possible hazards of use on human health, safety and performance (ISO, 2010). Facilitating the timely and successful completion of the project within budget (Maguire, 2001; Norman, 2013), and reducing customer support and training costs can also result from the integration of HF/E in design (Maguire, 2001; Österman, 2012). Reducing the risk of missing stakeholder requirements and of the system being rejected by its users (Maguire, 2001; Norman, 2013), therefore increasing the acceptance, commitment and trust of the users towards the system (Maguire, 2001; Österman, 2012) can augment technical, commercial and competitive advantage, and improve the image and reputation of the organization (Maguire, 2001). Some of these benefits are further corroborated by the results in this thesis.

Based on the ISO 9241-210:2010, there are five design stages and six key principles that should be considered if the benefits described above are to be attained. The HCD stages are shown in Figure 1:

- Planning the HCD process
- Understanding and specifying context of use
- Understanding and specifying user requirements
- Producing design solutions to meet context of use and user requirements
- Evaluating the design against requirements
- Iterating if needed or finalizing

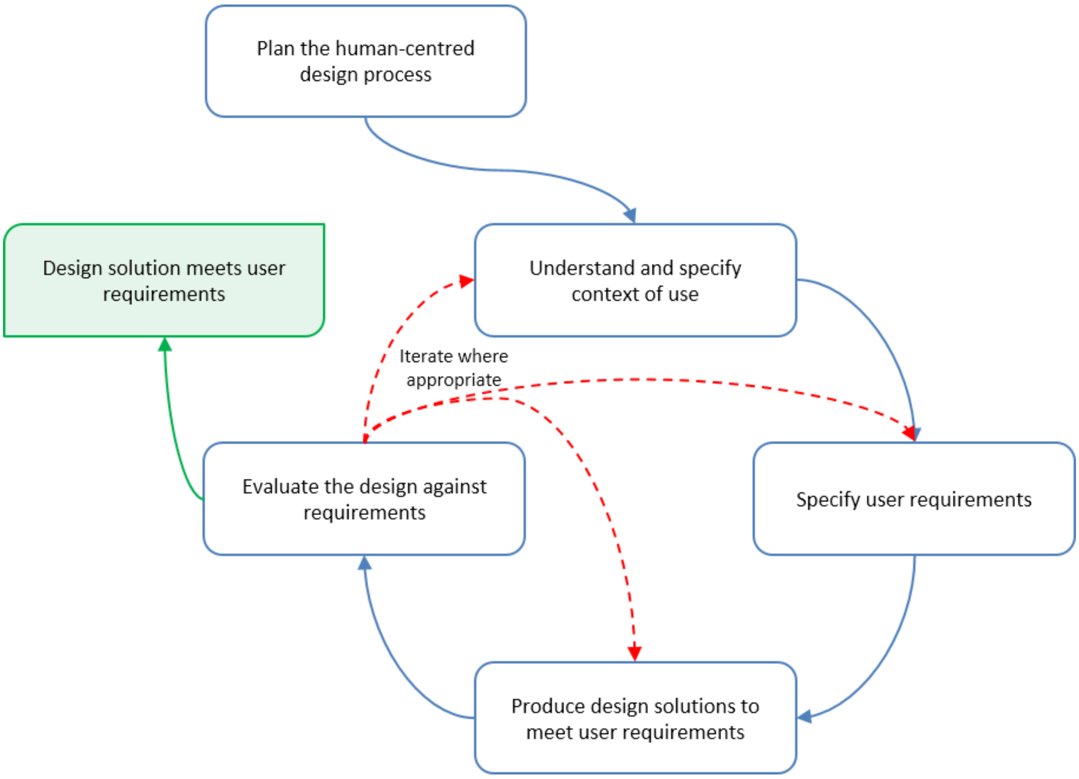


*Figure 1. HCD cycle for interactive systems, based on the ISO 9241-210:2010.*

This HCD cycle complements other design approaches employed by the designer or engineer. For example, the general model for ship design based on Evans (1959) used by naval architects can be complemented with HCD (see de Vries et al., 2015). HCD should be ensured throughout all design stages (concept, preliminary, contract, and detail design), as well as throughout the whole lifecycle of the system, product or service (ISO, 2010). The following six principles are to be realized in all five HCD stages (the results in this thesis will reflect mainly on the second HCD principle, regarding the involvement of users, and partially on the last principle, regarding the multidisciplinary perspectives in the design team):

- Explicit understanding of users, tasks and environments
- Involvement of users throughout design and development
- User-centred evaluation-driven and -refined design
- Iterative process
- Addressing the whole user experience (UX)
- Including multidisciplinary skills and perspectives in the design team

As those who pay for the design project are not necessarily the end-users, HCD has made designers' claims more credible when speaking for end-users' needs (Koskinen et al., 2011). To other designers, especially those more artistically oriented, HCD hasn't always been seen as immediately useful. It has been perceived as a research-driven approach rather than design-driven (Koskinen et al., 2011). Another issue with designing for a user is the focus on the cognitive functions and predetermined usage patterns of the product, departing the product from possible future alternative usages that are difficult to predict as they emerge during usage within social interactions and settings (Giacomin, 2014). This is one of the reasons that made Norman (2005) shift his support of UCD towards Activity Centred Design (ACD) instead, as he believed that by focusing on the activities in which the product can be used, one can open up for all these future usage possibilities that the sole focus on the user does not enable. But others have suggested that this is but a misconception of UCD, which encompasses the principles of ACD and more (Williams, 2009). Today, HCD is one of the three main design movements that govern the world of design and the one to put the human first (Giacomin, 2014), having been designated by the ISO and the IEA as the official approach for the integration of HF/E and usability principles, knowledge, and techniques in design practice. HCD has become an overarching approach or a basis for usability, empathic design, design for customer experience, emotional design (Giacomin, 2014), design thinking (Brown, 2008), co-design (Sanders & Stappers, 2008), user centred systems design (Gulliksen et al., 2003) or human centred systems design (Gill, 1996), activity centred design and goal directed design (Williams, 2009), and systemic design (Lurås, 2016). Giacomin (2014) describes the design paradigm shift into HCD from "*what began as the psychological study of human beings on a scientific basis for purposes of machine design*" to what became "*the measurement and modelling of how people interact with the world, what they perceive and experience, and what meanings they create*" (p.612). HCD is being more and more understood as a design philosophy, emphasizing the metaphysical aspects of design and the design process as a conjoint creative practice:

> *"a multidisciplinary activity which has as its ultimate goal the clarification of purpose and meaning, and is fully consistent with the assertion that design itself is a pragmatic and empirical approach for making sense of the world around us (…) a pragmatic and applied approach for identifying 'ideological opportunities' and for performing 'cultural design' (…) Today's human centred design is based on the use of techniques which communicate, interact, empathize and stimulate the people involved, obtaining an understanding of their needs, desires and experiences which often transcends that which the people themselves actually realized. Human centred design is thus distinct from many traditional design practices because the natural focus of the questions, insights and activities lies with the people for whom the product, system or service is intended, rather than in the designer's personal creative process or within the material and technological substrates of the artefact (…) human centred design leads to products, systems and services which are physically, perceptually, cognitively and emotionally intuitive."*
>
> Giacomin (2014, p.610)

## 2.5 The Human Element

In 1997, the IMO initiated and adopted a new resolution, A.850(20), dedicated to promoting the safety of life and work at sea and environmental protection – *The Human Element* (IMO, 2003). This resolution provides the following definition for human element:

> "*The human element is a complex multi-dimensional issue that affects maritime safety and marine environmental protection. It involves the entire spectrum of human activities performed by ships' crews, shore based management, regulatory bodies, recognized organizations, shipyards, legislators, and other relevant parties, all of whom need to cooperate to address human element issues effectively.*"
>
> IMO (2003)

According to this definition, the importance of a concerted effort from all maritime stakeholders towards solving HF/E issues is recognized. The verb “cooperate” suggests communication between stakeholders, in order to “address human element issues effectively”. Although this is part of the IMO’s vision and principles, it is a work in progress.

Within the Human Element resolution, the IMO established principles for the promotion of a safety culture and seafarer professionalism, namely on safe manning, fatigue, working groups, work and rest hours, and formal safety assessments. Some of the operational codes and conventions to address human element principles are the International Convention for the Safety of Life at Sea (SOLAS) and its International Safety Management (ISM) code (IMO, 1974), and the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW Manila) (IMO, 2010). The Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) (IMO, 1972), the International Convention for the Prevention of Pollution from Ships (MARPOL) (IMO, 1973), and the International Convention on Maritime Search and Rescue (SAR) (IMO, 2004) also have human element implications.

The safety and efficiency of sea transport depends greatly on good design, construction and operation, yet there remains room for considerable improvement (Earthy & Sherwood Jones, 2010; Kataria et al., 2015). Between 75-96% of marine accidents have been associated with ‘human error’ (Hanzu-Pazara et al., 2008; Veysey, 2013) as well as one-third of marine accidents have been linked to poor design (Grech et al., 2008). In a recent study by Kataria et al. (2015), two-thirds of the 129 publically available maritime casualties analysed were associated with human-machine interaction and automation issues due to poor design. These issues draw attention to the need for HF/E integration in the sector.

HCD is well consolidated in ergonomics, computer science, artificial intelligence (Giacomin, 2014), interaction design and industrial design (Koskinen et al., 2011). Despite the efforts of the IMO to address human element issues (IMO, 2003), the practice of more human-centred, participatory approaches remains limited in the maritime domain. This is believed to be due to the predominance of the engineering sciences in this sector, and to hesitancy towards cultural change and investment in the soft sciences, making the conveyance of a usability mind-set difficult (Petersen, 2012) and hence the practice of human-centred and participatory approaches. What is more, maritime authorities and regulatory bodies propose regulations whose compliance is generally voluntary and explained prescriptively and at a high-level, failing to provide sufficient guidance on how to incorporate such knowledge into the design of merchant vessels, and thereby proving difficult to follow up on (Kataria et al., 2015; Rumawas, 2016). Besides, the making of HF/E- and safety-related IMO regulations is often the direct response to maritime accidents, and a more systemic and proactive approach to addressing HF/E issues seems to rarely happen (Lützhöft et al., 2011; Schröder-Hinrichs, Hollnagel, Baldauf, Hofmann, & Kataria, 2013).

Usability testing and systemic intervention programmes may still not be common current practice across the maritime industry, but it is believed that growing automation and technological complexity will mandate these to be more frequent and reliable, and to gain increasing acceptance in future design and development (Grech et al., 2008). This is evidenced by the human-centred focus of current programmes such as E-navigation (IMO, 2014a), although no fully approved guidelines for the application of HCD within ships and marine technology currently exist. Within the IMO’s *E-navigation strategy implementation plan*, draft guidelines on HCD and Usability Testing, Evaluation and Assessment (UTEA) for e-navigation systems are currently under consideration (IMO, 2014b).

Additionally, an online platform with guidelines to the HCD framework began being developed within the CyClaDes project by the classification society DNV-GL and international partners to incentivize and support marine designers and other maritime stakeholders to consider HF/E (van der Merwe, 2015). Research has also investigated HCD of ships, ship workspaces and crew work demands including general arrangement (Mallam, Lundh, & MacKinnon, 2015); the ship's bridge (Bligård et al., 2014), engine department (Mallam, 2014); and the integration of HF/E and HCD into the general model of ship design by Evans (1959) for an offshore wind farm installation vessel project (de Vries et al., 2015).

## 2.6 Maritime Stakeholders

Although this thesis focuses specifically on seafarers as the end-users of ships and ship systems, it is important to consider the wider range of maritime stakeholders that the HCD approach would affect or be affected by. The maritime industry is global and comprises a vast and complex network of stakeholders (Lurås, 2016; Lützhöft et al., 2011). The needs and roles of four main stakeholder groups have, though, been highlighted in the CyClaDes project regarding the integration of HF/E in the domain. They are the seafarers (users), the naval architects and ship systems designers, the authorities and regulatory bodies, and the ship-owners/ship operators. The needs of the seafarers may be met by implementing a participatory approach throughout the design and operational lifecycle of ships and ship systems; more usable workstations and processes; and new training programmes for crew members. In order to accommodate methodologies for usability and for the incorporation of user input, naval architects and ship systems designers require guidelines and best practices for a human-oriented design of safety-related aspects of ships and ship systems. Authorities and regulatory bodies can contribute by developing an approach for a more comprehensive consideration and analysis of the human element in the context of the rule-making process; and by providing human element training and/or tools for assessors. Ship-Owners/Ship Operators, in turn, may contribute by considering end-user needs during acquisitions or new orders; by providing training for their crews and recognition of best practices.

# 3 Methodology

## 3.1 Methodological Overview

The work presented in this thesis was carried out during 2013-2016 at the Department of Shipping and Marine Technology, Division of Maritime Human Factors and Navigation at Chalmers University of Technology. The research was part of the CyClaDes project, which involved a multidisciplinary team to promote the increased impact of the human element across the design and operational lifecycle of ships and ship systems, by focusing on where the barriers to HF/E and HCD integration occur; and how to best produce, allocate, disseminate and apply HF/E and HCD knowledge, methods and techniques within the overall context of the maritime domain (CyClaDes, 2015b). This thesis explores how end-users perceive the potential of user participation in design; what they can contribute with in design practice and what dimensions of maritime design and operations they prioritize.

To address the research questions, literature reviews and qualitative research methods were employed for data collection and analysis, conducted within a sequence of three articles. Articles I and II utilized focus group interviews for data collection and Grounded Theory approach for data sorting, reduction and analysis (Corbin & Strauss, 2008) to uncover end-user perceptions of participatory and human-centred approaches applied to a marine design context. Article III presented a literature review of human-centred design-, human factors/ergonomics- and usability-related concepts to promote and propose HCD application in traditional naval architecture.

## 3.2 Methodological Tools

### 3.2.1 Focus Group Interviews

Focus group interviews were used as the data collection method in Articles I and II. A focus group interview is a collective interview rather than individual. It is a carefully planned occasion to which a selected group of members of the public (typically between five and twelve) are invited to share and discuss their perceptions on a particular topic for a couple of hours (Patton, 2002). The discussion is steered and encouraged by one moderator, and often aided by an assistant moderator (Langford & McDonagh, 2003; Maguire, 2003; Patton, 2002). The group members are selected on the basis of their connections to the topic under debate. The nature of this method is participatory, enabling the participants to engage in the discussion (Langford et al., 2003) and to build on each other's views, enriching the discussion and the data (Patton, 2002). As a series of sessions should take place to confirm that any identified patterns are consistent (Langford & McDonagh, 2003), Articles I and II comprise a total of two focus group interviews, each with a different participant sample, for data collection.

### 3.2.2 Grounded Theory Analysis

Grounded Theory is considered an abductive approach to qualitative analysis (Czarniawska, 2014) developing new theoretical constructs and concepts from qualitative data about the social reality rather than testing existing ones (Corbin & Strauss, 2008; Patton, 2002; Taylor & Bogdan, 1998). The first pieces of data should indicate what to collect next and which direction to go (*theoretical sampling*) (Corbin & Strauss, 2008; Orr, 1990). In practice, this method is based on a set of coding procedures (through different types of analytical tools) to interpret the data. The coding of the data consists of a meticulous inspection of the data in search of categories or symmetries of phenomena, intended to increase the rigor and objectivity of qualitative and ethnographical data (Corbin & Strauss, 2008; Orr, 1990). Data may be collected from focus groups or individual interviews, observations, documents (e.g., historical, media, diaries), multimedia files, among others. These data sources may be combined to explore a topic further.

Articles I and II utilized different analytical tools for grounded theory. The first article combined the data of both focus groups, corresponding/confirming a list of dimensions found in literature with the actual data. The second article draws upon the results of focus group 2 to present a conditional/consequential matrix (Corbin & Strauss, 2008). Both articles, however, have considered qualitative, quantitative and structural content analysis by reducing the data into concepts/categories, having the participants rank them in order of prioritization during the focus group sessions, and developing a representation of the relationships between concepts/categories (Millward, 1995). Both analytical processes began with data collection and progressed continuously and iteratively (Corbin & Strauss, 2008; Czarniawska, 2014).

## 3.3 Procedures

### 3.3.1 Article I

Both focus group interviews were exploratory. The discussion began with one prearranged question from the main moderator leading the session. Both sessions took place in a room with the fitting conditions and tools. An assistant moderator aided the session by taking comprehensive notes, operating the recording devices, handling the various hand-outs and intervening in the discussion occasionally with questions or clarifications when appropriate (Krueger & Casey, 2009; Patton, 2002). The sessions were audio-recorded following the signature of a written consent form by each participant. A second questionnaire was also handed out to each participant to gather demographic details.

***Focus Group 1***

Focus group 1 piggybacked on a workshop associated with shaping ships for people, organized by the Nautical Institute and Chalmers University of Technology. A larger number of participants were gathered for the workshop, but for the focus group interview a total of eleven male participants were recruited. Their backgrounds were considered in advance: among them two were still active in seafaring jobs, eight were no longer exercising seafaring jobs (three of which working in different activities, and another five retired); and only one of them had never had any experience at sea but was working for the sector as a sales manager. For those with time at sea, it ranged from 5-50 years, with a mean of 24 years (*sd* = 15.5). Nine of the participants reported having experience from more than one ship type, and four reported pilotage experience. Ten of the participants were of Scandinavian nationalities and one was from Western Asia. They were between 40-71 years old, with a mean age of 56 years (*sd* = 12.2).

As this focus group session occurred within a bigger event on the subject of shaping ships for people, it was important to brief the participants shortly on the concept of HCD in order to set the ground for discussion, before the focus group question was introduced. Afterwards, the probe that initiated the discussion was:

*Considering your experience working and living on ships, and the previous briefing, what do you perceive are the benefits of applying human-centred design to ships?*

Following this question, each participant was asked to write individually a list of potential HCD benefits for seafarers. They were given approximately 10 minutes for this task and then proceeded to a group discussion that lasted for 50 minutes more. The main moderator was directing the discussion as well as introducing follow-up questions and creating a mind map on the whiteboard with the ideas shared and debated (see Figure 2). Finally, the participants were asked to individually prioritize one or two benefits that they considered the most important for the seafarers.

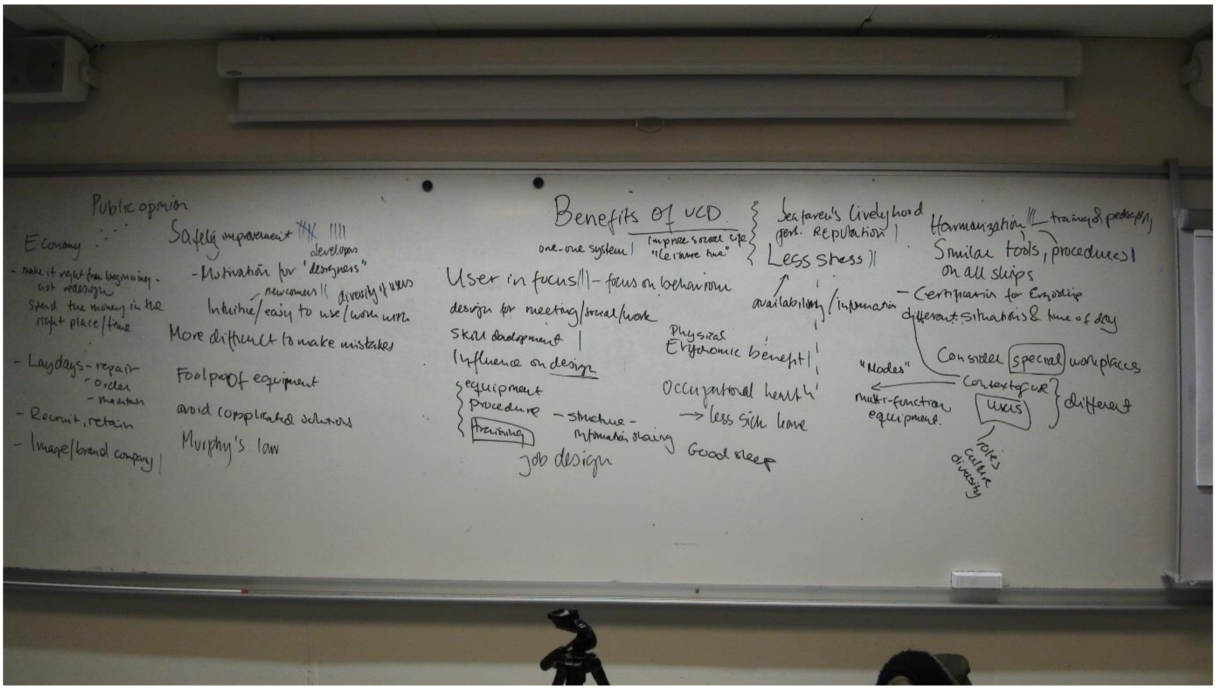


*Figure 2. Gathering of ideas on the white board during Focus Group 1.*

***Focus Group 2***

For focus group 2, a sample of ten Swedish university students was invited to participate. The students' backgrounds were considered prior to selection: they were studying the same academic programme to become Master Mariners and had between 6-50 months of experience at sea on different ship types, with a mean of 14,5 months (*sd* = 12.6). The participant with the most time spent at sea had been involved in interface design before, and the remainder had never had any connection to design. Of the participants, 70% were male and 30% female, with ages between 22 and 32 years (a mean age of 25 years (*sd* = 3.7)).

The students recruited for this focus group session were registered in a maritime human factors course, but hadn't yet been given any lectures on participatory ergonomics/design nor HCD. They were asked at the focus group interview to discuss the benefits of end-user participation in maritime-related design projects:

*Identify success factors of user involvement in the design process of the work environment and equipment onboard.*

There was a decision to pose this question differently from that of the previous focus group session as to avoid any possible ambiguity related to the concept of HCD, which could have been completely new for the participants. Also, this question was directed at what makes user participation in design both successful and beneficial.

As the participants discussed the success factors and benefits, they were listed on the whiteboard (see Figure 3). Then, the participants were asked to collectively prioritize the ten most important factors and to reflect upon the degree to which each of the prioritized factors exists in reality today, in terms of whether they are commonplace or not at all.

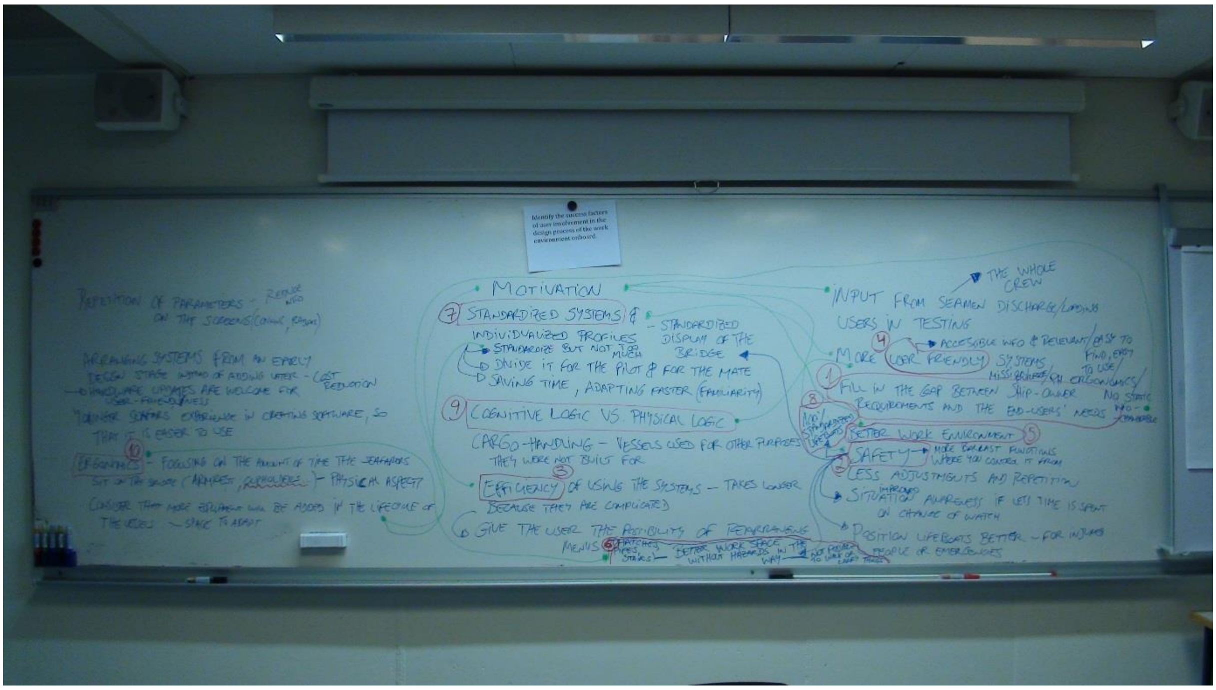


*Figure 3. Gathering of ideas on the white board during Focus Group 2.*

***Data Analysis***

For data analysis, the audio-recordings of both focus groups were transcribed and analysed conjointly along with the field notes and the mind maps drawn on the whiteboard during the focus group sessions. The transcriptions were iteratively transformed into benefit groupings and then linked to HF/E dimensions of ship design found in literature. The results were, thus, organized in Article I in a Russian doll-like manner, being stacked as (a) the benefits mentioned by the participants, (b) the different categories of benefits, and (c) the HF/E dimensions of ship design matched from literature (see Figure 4).

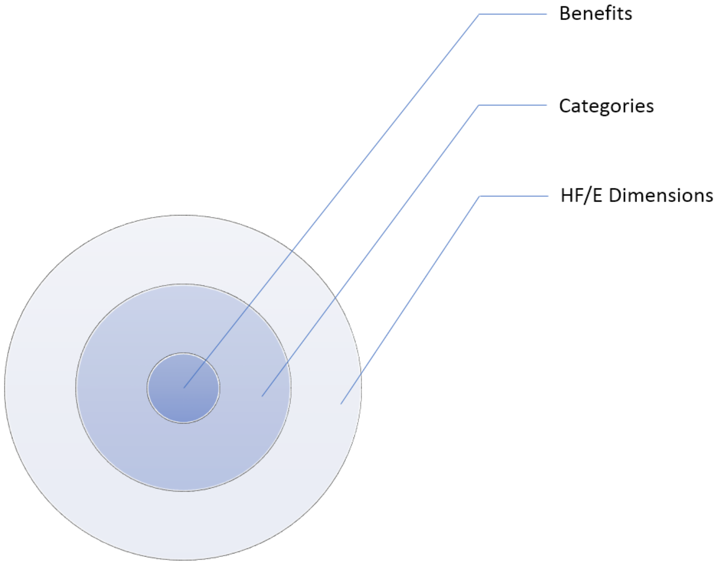


*Figure 4. Organization of results in Article I.*

### 3.3.2 Article II

For the description of the participant sample and procedure of the focus group interview in Article II, see *3.3.1 Article I*. Although Article II discusses one of the same focus group interviews in Article I, the analysis takes a difference perspective (Patton, 2002). In order to capture the views of a second, younger, sample of users, a group of students of the Master Mariner programme at Chalmers University of Technology was selected. Whereas Article I lists HCD benefits at different levels that naval architects and ship systems designers should take into account in their future design projects, Article II proposes a conditional/consequential matrix of pre-requisites that should facilitate the attainment of such benefits.

### 3.3.3 Article III

Article III is a literature review and the introductory chapter of a marine design practitioners' handbook for HCD. The purpose of this review was to gather published knowledge about HF/E, HCD and usability, and propose the integration of HCD in traditional naval architecture. Key concepts, theories and problems in the consulted references were studied and extracted. The review was limited to works in English, and they ranged from scientific, industry-based and standards reports. Books, conference proceedings and online libraries and databases were utilized for scientific publications, whereas industry-based documentation and standards were accessed on the official websites.

# 4 Results

## 4.1 Article I: HCD benefits in terms of HF/E dimensions

The participants considered work and life at sea, the work environment and equipment onboard ships, and discussed the potential benefits of a human-centred, participatory approach to design. The benefits were organized in groupings/categories, as shown in Figure 5.

**Physical Ergonomics & Usability**
e.g., space to move objects; optimized lay-outs; available and accessible information; intuitive systems; day and night modes; cognitive vs. physical logic; comfort in common areas and accommodation

**Efficiency**
e.g., reduced repetition of parameters on different screens; integrated bridge systems; ease of use, time saving and less need for manuals when systems are intuitive

**Shaped Work, Procedures, Operations**
e.g., harmonized procedures across ships for avoiding mismatches and mistakes; deciding on off-duty hours for the seafarers – *"today seafarers often have to be available at all times"*

**Superior Training**
e.g., harmonized training across cultures for facilitating the work of mixed crews; making training programmes user-centred: how to best prepare the seafarers

**Harmonization & Standardization**
e.g., harmonized bridge equipment for avoiding incongruences between manufacturers; standardized bridge systems with chance to save personal preferences to support familiarity across ships; standardized training, procedures and lifeboats

**Flexibility/Adaptability**
e.g., adaptable equipment to the context (e.g., docking, night); systems that can adapt to the individual – *"not static"*; adaptable vessels for different purposes to promote safer operations

**Improved Environment**
e.g., common recreational spaces; better working and social environment

**Safety**
e.g., standardized lifeboats and safety procedures; reduced slips, trips and falls by removing physical hazards

**Stakeholder Communication**
e.g., reduced communication gap between stakeholder requirements

**Career Development**
e.g., protected seafarer reputation by less human error; skill development with better designed systems

**Satisfaction & Motivation**
e.g., lower stress; enhanced motivation through user involvement; *"happy crew"*

**Cost Reductions**
e.g., spending money on the right things at the right time; less need for redesigns if the design is well done from the start; reduced accidents and costs on sick-leave, on training if systems are more intuitive, and on maintenance if the design works; prevention of lay-days

**Enhanced Corporate Image**
e.g., better public image and reputation for the company affects the seafarers working for it positively

*Figure 5. Categories of benefits of a human-centred and participatory approach.*

These findings show that the participants perceived human-centred, participatory approaches to design to be beneficial at the physical, cognitive, psychosocial, organizational, and socio-political levels.

From a physical ergonomics perspective, examples included making space to carry equipment around without hazards in the way (pipes, ceilings, gaps, steps); positioning equipment where it is more appropriate for use by the right users (e.g., *"the second mate has to stretch to reach the VHF"* when the second mate is often the one to utilize the VHF more often when sitting on the bridge); or even simple things as having cup holders to keep computers and screens from getting damaged when liquids spill with ship movements.

Cognitive-related ergonomics examples were also provided in terms of the software systems having easily accessible information; the interfaces displaying less unimportant information, having straightforward menus, and being adapted to purpose (*"mission-specific"*; *"not all parameters on the screen are important at all times"*) and adaptable to the individual using it (*"not static!"*). Considering the integration of the cognitive with the physical is also a factor of importance, e.g., *"when tightening, you pull the handle towards you; when you tighten with the remote control, you push it away from you, and that's bad logic".*

Organizational aspects should also be designed with the user in mind, such as making basic training and basic safety equipment and procedures standardized across ships and crews to avoid mismatches and mistakes. Some aspects of practice must also be considered with regards to workload, working and resting hours. Participants claimed that *"today seafarers often have to be available at all times"*, on-call even when off-duty, which does not allow them to fully benefit from their resting time.

From a psychosocial perspective, generally more ergonomic living and work areas, equipment and procedures can increase motivation and satisfaction, and facilitate a better social environment. Ultimately, these benefits would increase safety, which considered from an organizational and socio-political perspective would reduce company costs, financially and in terms of reputation and marketplace.

The benefit categories in Figure 5 are potential areas of improvement in the maritime industry. The consideration of these categories in design and the realization of the benefits will have a positive impact over HF/E dimensions of ship design, such as those shown in Figure 6.

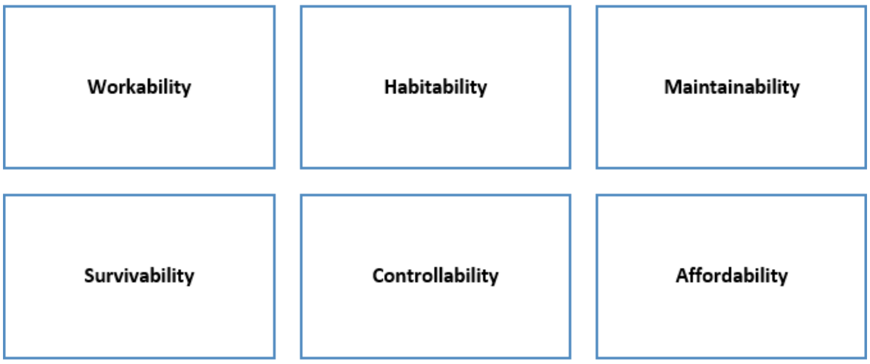


*Figure 6. HF/E dimensions of ship design that can gain from the benefit categories.*

The same category can have a simultaneous impact on multiple HF/E dimensions (e.g., better *Physical Ergonomics & Usability* could improve both *Workability* and *Controllability* onboard ships). The HF/E dimensions are defined as:

- **Workability** refers to the conditions onboard that help the seafarers fulfil their tasks, including equipment (hardware and software), materials and procedures, physical and social environments, information, handbooks, and language (Lloyd's Register, 2008; Rumawas, 2016);
- **Habitability** refers to adequate, comfortable and practical accommodation, cooking and washing facilities, storage and recreational spaces having regards for size, shape, gender, culture and environmental stressors such as noise, temperature and vibration (Lloyd's Register, 2008; Rumawas, 2016);
- **Maintainability** refers to the conditions onboard that allow seafarers to perform the necessary maintenance of the ship, including access, tools, through-life support for the lifespan of the ship, and the design of operational maintenance tasks to be safe and efficient (Lloyd's Register, 2008; Rumawas, 2016);
- **Survivability** refers to the availability of adequate equipment and facilities for firefighting, damage control and lifesaving, and the capabilities of the crew to ensure safety of crew and passengers (Lloyd's Register, 2008; Rumawas, 2016);
- **Controllability** refers to integrating users with equipment and interfaces, and appropriating layout of work stations, communication facilities, controls, displays, alarms, lights, etc. to allow the seafarer to perceive the status of machines and systems and provide fitting responses (Lloyd's Register, 2008; Rumawas, 2016).
- **Affordability** refers to the total ownership costs associated with system/technology redesign, manpower, training, human support, and reduction of errors and accidents (Novak, Kijora, Malone, Lockett-Reynolds, & Wilson, 2010).

Article I focused on the listing of potential benefits of human-centred, participatory approaches in the maritime domain more than focusing on how they occur or on what needs to be considered within HCD to allow them to occur. The latter were examined further in Article II.

## 4.2 Article II: Conditional/consequential matrix of success factors for maritime HCD

Article II showed that once certain design considerations are accounted for, positive outcomes will follow as a consequence (see Figure 7).

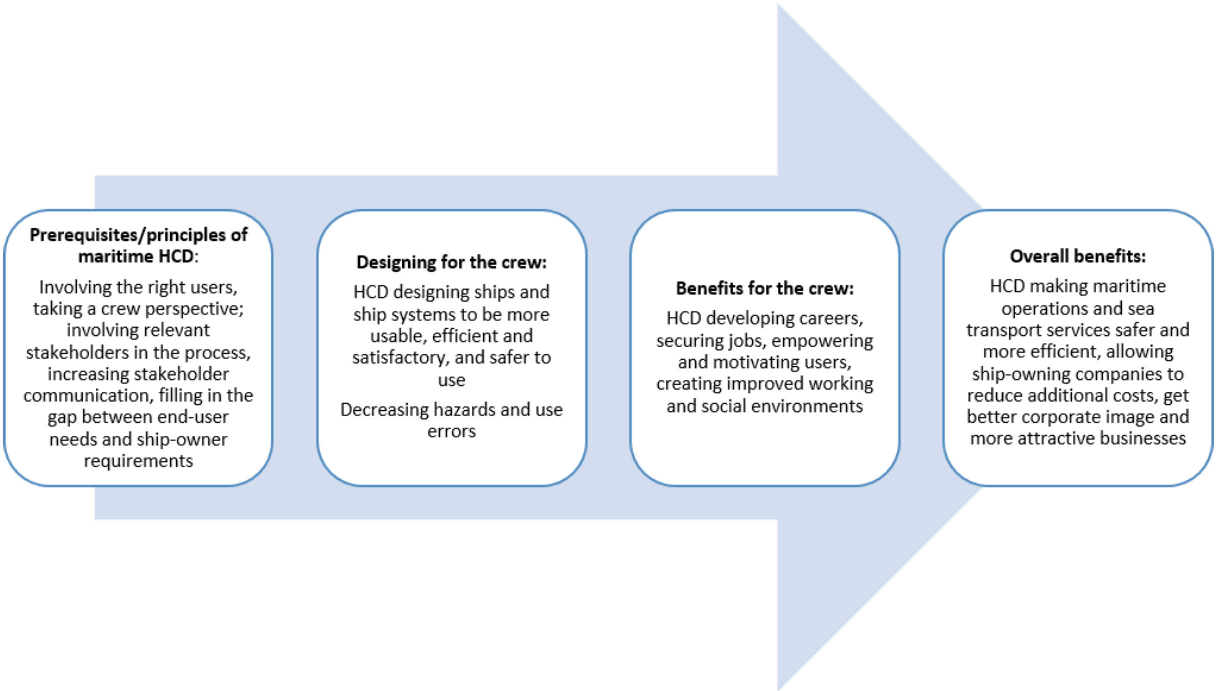


*Figure 7. Conditional/consequential matrix of pre-conditions and subsequent success factors of user participation in marine design processes.*

The participants considered bridging the gap between end-users' needs and ship-owners' demands to be the foremost benefit of user involvement in the design process. As the communication between ship-owners, designers and users is enabled through a participatory approach, "*a foundation is built for all the other success factors that follow*". The participants also stated that *"communication between users and designers can make designers more aware that the users are the seafarers, not the ship-owners (…) there is a difference between the people who use the interfaces and those who tell them to use them".* The participants proposed tools for facilitating user input, such as focus groups, paper mock-ups, interviews and simulators. In the sense of user communication with other stakeholders, it was also suggested that having influence over the regulatory bodies such as the IMO could help better suit certain rules and regulations to the actual work and experiences onboard ships. User input in purchasing actions could also help ship-owners make the right choice for the intended type of operations.

Ergonomics issues might differ for different types of ships and different sections of the ship, and consequently the "right users" must be invited to participate in design, including Able Seamen (AB) and other technicians/ratings. The age group might be an important factor to consider if it has an impact on the seafarers' familiarity with technology: *"there are senior officers getting involved in the design process, but you also need younger people testing this, because they don't have the same perspective of the system – younger people have more experience with computers",* as well as levels of experience and hierarchies.

Provided that these prerequisites are realized, expert user knowledge can be shared with the design team and incorporated to develop design solutions (*"someone who will sit 8 hours in a row in the same position might be able to say more about ergonomics than those who design it"*). Consequently, ergonomic improvements to the onboard work settings can occur (e.g., *"it feels like three technicians created one screen each, because you have speed and heading on three different screens"; "rearrange reality down to the controls of the mooring lines, like when you tighten the mooring lines, you pull it* *towards you, but when you tighten with the remote controls, you push it away from you"*; *"something that could take 10 minutes takes 45 instead (…)"*). Such changes could result in improvements on all dimensions mentioned in *4.1 Article I: HCD benefits in terms of HF/E dimensions*. The involvement of users should not only help improve design, but also incite users' intrinsic motivation and a feeling of empowerment as their input becomes materialized.

The increased safety and efficiency of maritime operations were the most valued end-results of participatory design approaches by the participants. They also listed benefits for ship-owners in terms of affordability, such as reduction of casualties and costs, provided that things can be done properly the first time, avoiding unnecessary costs for rearranging and retrofitting. All in all, it is not just about the financial sustainability of the company, but also about sustainability at the social and environmental levels.

The participants emphasized that they believed that there was still room for improvement on all levels. For instance, the safety aspect of a product is usually regulated by IMO conventions and it is difficult to give user input on this, hence the importance of more user representativeness and influence across the maritime network of stakeholders.

## 4.3 Article III: Integrating HCD in naval architecture and ship systems design

The findings from Articles I and II allowed for a better understanding of the range of HF/E dimensions in the maritime domain that would benefit from a human-centred, participatory approach, as well as of aspects of user participation to be considered when in the maritime domain. These findings, considered along with literature in the matter of HCD helped shape Article III, with the intent of introducing naval architects and ship systems designers to the integration of HF/E in design. Therefore, Article III encompasses not only the cycle and principles of HCD as they are depicted in literature, but it also considers the HF/E dimensions found in Article I and the important aspect described in Articles I and II of promoting safety onboard.

# 5 Discussion

## 5.1 Drivers for Maritime HCD

The discussions held by the two participant samples showed that the participants perceived HCD as value-added for life and work at sea at all different levels of analysis: the physical, cognitive, psychosocial, organizational and socio-political. The benefits of a human-centred, participatory approach become a catalyst for ship-owners to invest in HF/E, regulatory bodies to incorporate it, and designers to employ it.

In the ranking task, participants commented that the benefits were linked rather than isolated; that some were results or outcomes of others. They considered filling the gap between end-users' needs and ship-owners' requirements as the primary benefit of user involvement in the design process, representing a platform for all the other benefits to be realized, including the most crucial goal: safety. The objective of HCD is to study and identify users' needs by fostering open communication between them and the design team, and that this results in invested, encouraged and empowered users (Maunder, Marsden, Gruijters, & Blake, 2007). Putting money into the right thing from the beginning should enhance organizational learning, prevent casualties, reduce unnecessary expenses and promote a more efficient crew. This can, in turn, highlight the reputation of the organization and make the business more attractive (Hendrick, 2003). The latter is also believed to help retain competent personnel and help create competitive strength in the company and the sector (Österman, 2012; Österman et al., 2010). From this perspective, positive outcomes for the seafarers would turn up as positive outcomes for the ship-owners and vice-versa.

Österman (2012) presents a value proposition resulting from the integration of HF/E in the maritime domain, at four different levels: society, sector, company, and employee. For the seafarers, improved performance, health and well-being would be an advantage. As a consequence, the reduced number of work-related accidents and incidents would lessen the negative impact on health care and society, and promote sustainability. The results from this research corroborate some of the author's findings.

### 5.1.1 HCD for Maritime Safety

In the ranking task, both participant groups settled that the best selling point of a human-centred, participatory approach is that it can help achieve maritime safety. This finding aligns with Maslow's Hierarchy of Needs, where safety is the main human motivation, assuming that the physiological needs are being met (Maslow, 1943). In fact, similarly to Maslow's theory, Giacomin (2014) suggests a pyramid model of HCD in which the design process should go from asking human physical and physiological questions to more metaphysical ones (meaning), prioritizing both safety and security. Safety and occupational health is a dimension of HF/E that comprises the conditions that allow the seafarers to work onboard safely and maintain their physical and mental health, including working and living environments, workload, procedures, and habits. System safety comprehends the integrity of the ship, crew, cargo and passengers, which requires risk analysis and management, and the identification of hazards and technical failures (Rumawas, 2016).

The IMO emphasizes the importance of maritime safety and security for the lives of the seafarers as well as for the environment. A number of IMO protocols and guidelines put focus on these matters (e.g., Human Element, STCW, ISM, SOLAS), as does The Nautical Institute and Lloyd's Register Foundation in the Alert! bulletin[2]. Thus, running safe operations onboard ships as the principal target

[2] http://www.he-alert.org/index.cfm

of the integration of HCD in ship and ship systems design is an important message that this thesis tries to convey to maritime stakeholders. A recent study by de Vries et al. (2015) showed that, for masters students of a Naval Architecture and Ocean Engineering programme at Chalmers University of Technology, subjected to HCD resources (including a previous version of Article III appended to this thesis) during a design project for a wind farm installation vessel, the key impact factor of HCD was safety. With safety of life at sea as the motive behind the design constraints imposed by regulations and classification society rules, the impact of HCD may be significantly amplified if its contribution to safe and efficient maritime operations is rightfully emphasized, especially at a time when the maritime sector is struggling more than ever to decrease overall risk in terms of human and environmental safety, performance and sustainable economy (de Vries et al., 2015).

## 5.2 Prerequisites for a Successful Integration of Maritime HCD

To attain the positive outcomes of HCD and participatory approaches, the participants proposed some prerequisites and/or principles that should be followed in the maritime domain. Seafarer input should be established for the design of tools, equipment, spaces, jobs, procedures, training, IMO regulations, as well as purchases by the ship-owning company to ascertain that these are in tune with the users' actual practices and needs. In other words, more and appropriate user representativeness in design and operations in the maritime sector is needed for successful HF/E integration.

Similarly to the ISO 9241-210:2010, the participants stated that the design process should be used as a means to bridging the communication and requirements gap between seafarers and ship-owners, who usually have different views of what is important and seldom have direct contact regarding design needs. So the presence of end-users and other relevant stakeholders in the design process can facilitate this communication, requirement elicitation and compromise. Involving the "right users" within a crew perspective is also a prerequisite. It does not suffice to involve senior officers in design. Younger officers may give essential input in usability testing as well, bearing in mind their technological experience and vision. Able Seamen (AB) and other technicians/ratings must equally participate in design processes for their respective departments onboard. For example, the deck department has been identified as representing the highest risk for occupational mortality on merchant vessels (Roberts, Nielsen, Kotłowski, & Jaremin, 2014) although more ergonomics attention has been given to the bridge and engine control room. Also conducted within the CyClaDes project, Kataria et al. (2015) has talked about how HCD should be expanded to fit the particular context of the maritime domain by accounting for the whole crew as an element in the sociotechnical system that is a vessel within the maritime transportation system, rather than focusing HCD to fit a single type of user without taking the wider perspective of all the crew members, who work together in several operations. This expanded version of HCD was termed Crew-Centered Design (CCD), and this holistic approach would come as a solution to increasing maritime safety, efficiency and having positive economic outcomes in shipborne operations and the design of ships. A well-defined user population is an advantage in realizing successful user involvement, even though this might not be easy to achieve (Olsson, 2004).

The findings in this thesis corroborate Österman et al. (2010), who identified various factors as being of importance for the achievement of a good work environment and safety onboard. These included organizational factors such as employee participation, which is believed to elevate crew morale and make the crew feel heard; it can improve business operations and even influence purchasing processes, as well as taking part in the making of IMO regulations.

In contrast, focus group 2 suggested that user involvement could also have drawbacks and these should be considered during design. On this note, the challenges presented in *2.3 Participatory Approaches to Design* must be considered. The participants advised that users might, for example, tend to mix up what they need and what they want, and therefore the design team should include the capacities to distinguish between them. Tools for facilitating user input were proposed by focus group 2, such as paper mock-ups, focus groups, interviews and simulators. These tools support the iterative design lifecycle and are better applied in the initial stages, being that it is more economical to make the suitable changes according to user feedback earlier rather than later (Maguire, 2001). Studies have also shown success in engaging users in the marine design process through interaction with various forms of digital and physical 2D and 3D representations (Bligård et al., 2014; Österman et al., 2011), and through basic HF/E methods such as task analysis and link analysis (Mallam, 2014). Either way, HF/E experts are needed as part of the design team to help do the translation of user needs into design solutions (Praetorius et al., 2015).

## 5.3 Standardization

From a design point of view, the participants repeated that standardization could be a solution to reduce errors and facilitate familiarity and work tasks. The standardization of systems across ships and ship types, and subsequent possibility of setting personal preferences through use of a personal key; the standardization of lifeboats, safety equipment and routines across ships; and the standardization of basic training across countries for the purpose of having uniform procedures and terminology when multi-cultural crews work together, were solutions seen to prevent incongruities and mistakes. The harmonization between bridge interfaces was also seen to eliminate unnecessary repetition, and make functions more integrated and compatible, such as the example of the Integrated Bridge Systems that have been developed by a number of manufacturers. *Standardized,* though, doesn't necessarily mean *good*, as the participants suggested. They advised that standardization can become "*counter-developmental*" in the sense of preventing manufacturers from implementing newer and improved solutions, being that standardized doesn't necessarily mean that it is a good design solution. The full standardization of computer systems that would allow for inserting a systems password or a key-card on any ship was debated as possibly not the most commercially viable alternative for manufacturers, considering it might imply the need for different manufacturers to design very similarly to each other and, in turn, lose competitive advantage. Additionally, once a system update is created, every ship would have to obtain it, which can represent a high initial investment.

Despite potential trade-offs, global standardization and harmonization of bridge design is one of the objectives of the IMO's E-navigation strategy to increase efficiency, safety and marine environmental protection (IMO, 2014b). Grech et al. (2008) list lack of standardization as one of the main human-machine interaction issues onboard ships, as well as lack of usability, information overload, poor ergonomic design and ergonomics integration in design, inadequate training and loss of skills, overreliance on technology, rapid technological change and superficial integration (see also Lurås, 2016 and Lützhöft et al., 2011). The authors advocate that standardization of equipment would open up for maritime manufacturers to be able to sell all over the world and for international maritime operations to save costs and gain usability benefits (Grech et al., 2008).

The participants also discussed how designs should account for possible future changes or needs in the usage of a ship or of a given system. This would allow for ships to be used for other purposes than the one it was imagined for (e.g., "*a car carrier being used for forestry products*") and maintaining the levels of safety with cargo-handling and ballast conditions, or to more easily adapt a piece of hardware through its lifespan (e.g., "*like Saab, adding extra buttons for lights and switches just in case*"). This notion of foreseeing the future potential of a product, service or system is in synch with HCD as described by Giacomin (2014).

## 5.4 A Model for Maritime HCD

Results from the data analyses in Articles I and II, as well as literature reviewed in Article III, are incorporated into Figure 8, designed with the original ISO 9241-210:2010 cycle for HCD in mind. Taking into account the sociotechnical systems models by Grech et al. (2008); Vicente (2006); and the HF/E value proposition by Österman (2012), this model brings together – and emphasizes – sociotechnical systems thinking and principles of ISO's HCD, for a more systemic, participatory and human-centred design philosophy in the maritime domain.

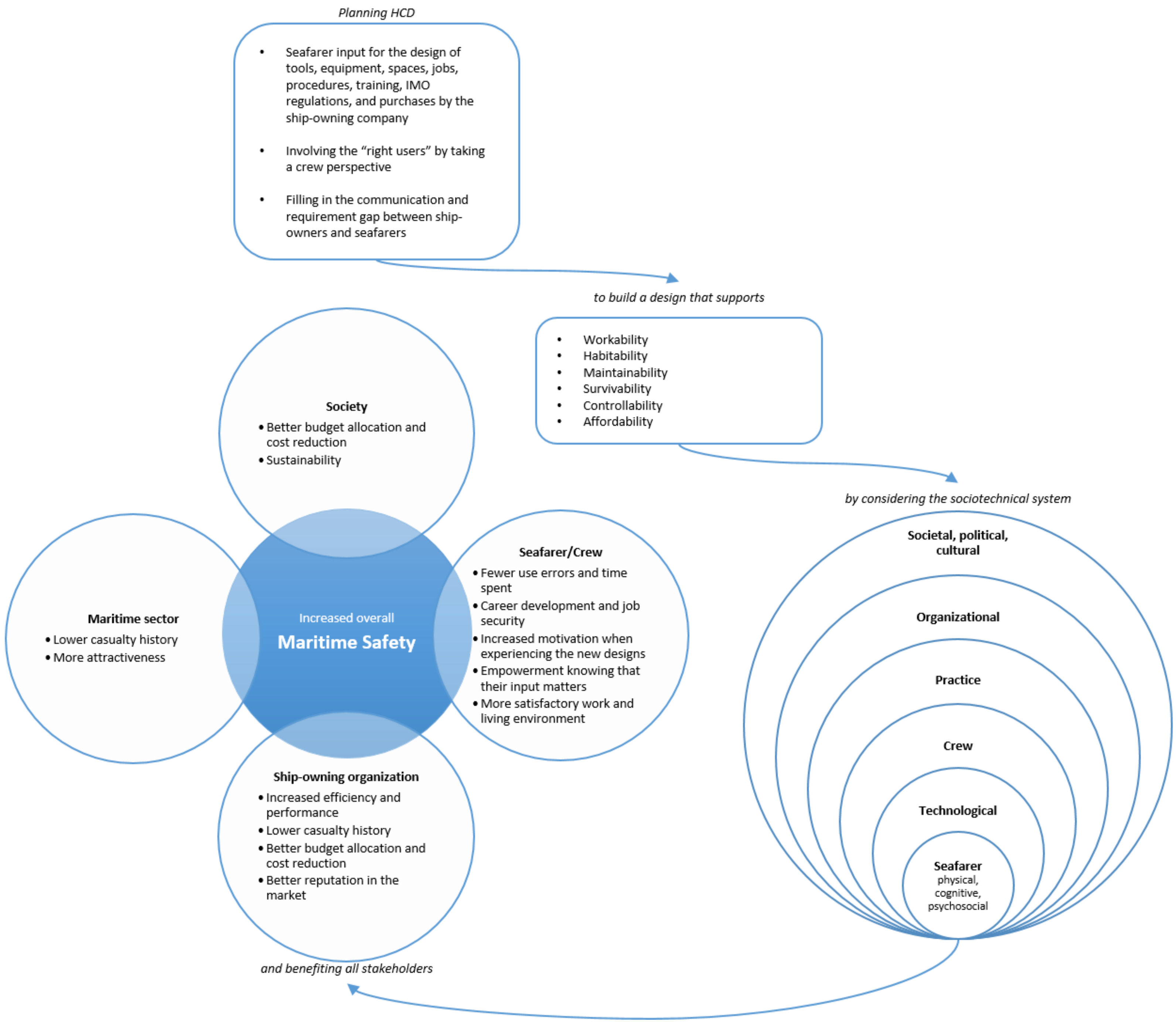


*Figure 8. A holistic model for maritime HCD with success factors and benefits.*

Design should begin with the identification of a human or societal need and then directed to mirror specific human factors (Vicente, 2006) considered from the context of the person, the job, and the organization and management (Grech et al., 2008), i.e. at the micro-, meso-, and macro-level. By taking a holistic perspective and integrating the HF/E dimensions of ship design as one of the criteria in the ship design spiral (Rumawas, 2016), the stakeholders involved can experience a plethora of benefits.

## 5.5 Methodological Discussion

### 5.5.1 Exploratory Qualitative Research Approach

This thesis and appended articles have based data collection and analysis on qualitative research methods. Qualitative research does not culminate into statistical or numerical data, but it suits the purpose of gaining a deeper understanding of a topic under investigation, especially those with a particular nature that cannot directly be quantified (Langford & McDonagh, 2003), such as the exploratory nature of this thesis. Qualitative research is aimed at discovering variables; not testing them (Patton, 2002), as well as focus groups are not meant to yield generalizable data, and therefore random sampling is not necessary (Millward, 1995). Future academics and practitioners are invited to build on the work presented in this thesis to understand specific user needs and ways in which HCD can be integrated in specific maritime projects. Replication of the methods utilized in this research is possible, but outcomes may vary according to the researcher applying the methods and interpreting results, the sample, and other factors. The obtained results tell the story of the participants' discussions through the eyes of the researcher (Corbin & Strauss, 2008).

### 5.5.2 Focus Group Interviews

***Focus Group 1***

The opportunity presented itself to assemble focus group 1 within an existing event. As the opportunity was taken, some conditions had to be accepted as they were, but this rendered them not fully controllable. For example, the fact that the event regarded HF/E issues could have caused bias to the results obtained at the focus group interview. However, the attendees of the event were there for interest in the topic, so perhaps this possible bias would have been impossible to control for. Also, participants in focus group 1 that did not belong to the cluster of seafarers, wanted to be present in the room, and they had relevant experience in regards to other professions in the maritime sector. The majority of participants in focus group 1 was middle aged. Especially for those who were already retired, their views might not entirely apply to the maritime domain of today and its technological advancements. On the other hand, they may have a superior view of how the industry works, how stakeholders relate to each other; of what is possible and what is important.

***Focus Group 2***

Focus group 2 was done with trainees in order to put together a larger variety of experiences. The variation of the participants' backgrounds with regards to types of ships, time at sea, etc., contributes to this study in the sense that more opinions may have been collected from a seafarers' perspective. The idea is that HCD focuses on the user and the context of use, but even if the context of use is specific to a section of the vessel, a type of ship, a system, a tool or a task, it must be generally usable to all types of seafarers. Crews today are considerably diverse and swap ships frequently, so it is difficult to determine who will work where. Therefore, design must account for all potential users.

***General focus group considerations***

There cannot be certainty of how much the sum of participants knew of HCD before their input in the focus group sessions, especially considering that most of them in focus group 1 took some part in marine design at some point of their professional careers, and the participants in focus group 2 had been receiving academic education in HF/E contents (although HCD hadn't yet been a topic). So it is discussed here that these groups might have been primed with influencing ideas regarding HCD prior to the focus group sessions.

Both sessions were limited in terms of time and it was not enough to fully confirm the categories and their relationships with the participants. Nonetheless, a preliminary analysis was done with the participants and, later on, categories and HF/E dimensions were refined and established according to literature in the matter.

The groups were not posed the problem equally, even though the objective was identical. The question for the first focus group may have been more distinctive than the second, due to the mentioning of the concept of HCD to a group of participants who were not HCD experts but had been participating in a related workshop within which the focus group took place precisely because of their interest in learning about shaping ships for the users.

Generally, focus group interviews may make some participants more reluctant to opening up about their thoughts and feelings in the context of a group, compared to being solely with the interviewer; and incite a false consensus during the group discussions for avoiding possible conflicts or for complying with socio-political correctness (Langford & McDonagh, 2003; Taylor & Bogdan, 1998). Moreover, being audio-recorded can have an effect on the participants' comfort and disclosure (Krueger & Casey, 2009).

Even so, focus group interviews facilitate access to group norms and processes that could be inaccessible outside of the group dynamics (Bloor, Frankland, Thomas, & Robson, 2001), as well as permit identifying, in a short period of time, a variety of perspectives (Langford & McDonagh, 2003) and whether the common group has consistent or divergent opinions about a given topic (Patton, 2002). The participants can make associations and reflect on things they would have not come up with on their own. The influence they have on one another and the disagreements and exchange of ideas and opinions produces richer conclusions than the individual parts (Langford & McDonagh, 2003; Maguire, 2001). On top of this, focus groups don't require much equipment and allow people to speak their minds in a somewhat informal way (Maguire, 2001).

Focus groups are a cost-effective way of identifying user requirements for products and systems (Langford & McDonagh, 2003), thus focus groups were utilized in this thesis to better understand maritime end-users, their opinions on the potential of user participation, and their general needs and priorities. Establishing user groups can be quicker and simpler than individual interviews or observations for discussing and understanding their current activities, ideas and needs (Langford & McDonagh, 2003). As focus groups were utilized here for the purposes of this research, they are recommended for further, specific and more in-depth, user requirements elicitation and for bringing users and stakeholders together in the HCD process (Langford & McDonagh, 2003; Langford et al., 2003; Maguire, 2001). Focus groups collect knowledge that can later be used by designers and engineers (Langford et al., 2003), as intended in this thesis.

### 5.5.3 Grounded Theory Analysis

The grounded theory analysis method was selected for its solid structure – and one of the most prominent in the field of social sciences (Patton, 2002). The use of this method helped to understand how seafarers believe they can benefit from being involved in the design of ships, systems, equipment and tools; it helped to build new theory and find the common denominators within and between the focus groups, extract categories, substantiate them with literature, and link them in terms of a sequential matrix. This analysis method also helped with making sense, visualizing and transmitting the raw data.

# 6 Conclusions and Future Work

The research in this thesis aimed to explore the perceptions of seafarers regarding the potential of and success factors for end-user participation in ship and ship systems design. By investigating these questions, a better understanding of the users, their priorities and needs was gained, which is a crucial step in designing to meet user needs (Langford & McDonagh, 2003).

The research involved a comprehensive literature review performed in order to explore the underlying concepts of HCD and its principles, and two focus group interviews took place with two different participant samples (composed by retired, active experienced and novice seafarers). With respect to Research Question 1, the findings in Article I contribute with a range of HF/E dimensions of ship design that would largely benefit from a human-centred approach, at a physical, cognitive, psychosocial, organizational, and socio-political levels, encouraging its integration in this context. Article II, in turn, provides an answer to Research Question 2. It conveys the novice seafarers' perceptions of which success factors/principles are required for the adequate practice of a human-centred, participatory approach in marine design projects, which would lead to the benefits discussed in Article I. Article III is a practical publication written with the intent of introducing naval architects and ship systems designers to the integration of HF/E in the design of ships and ship systems through HCD. This research allowed a window into (a) designs that seafarers struggle with and opportunities for improvement; (b) seafarers' needs and priorities; (c) how seafarers see human-centred and participatory approaches and their potential; and (d) how seafarers feel they can contribute to design. Pertaining to Research Question 3, this work deepens the knowledge of what is important in maritime design and operations, and gathers HF/E recommendations for naval architects and ship systems designers, ship-owners and regulatory bodies to incorporate in their agendas and lead the realization of the discussed benefits.

One of the main conclusions of the appended articles points at maritime safety being the paramount outcome of an HCD approach, serving as the main incentive for maritime stakeholders to integrate it and the main goal that naval architects and ship systems designers should design for, as well as a subject of continuous research. To fulfil the end-goal, the design process must empower the entire ship crew and facilitate stakeholder communication for better requirement elicitation and cooperation. The design must account for HF/E issues regarding human-technology interaction, physical layouts and hazards, as well as the design of work, rules, procedures and training, so as to achieve a more usable, workable, habitable, maintainable, survivable, controllable and affordable environment, and ultimately contribute to overall maritime safety. Design methods and tools were suggested to facilitate user-designer communication, such as the usage of prototypes and interviews. The standardization, personalization and adaptability of designs were also debated as means to increase efficiency and avoid mismatches.

While this thesis primarily focuses on end-users, it should be noted that the design and operational lifecycle of ships and ship systems should include the involvement of other relevant stakeholder groups that can also be affected by design and influence it. This work is intended as a complement and a starting point but not a replacement of appropriate and specific user and context of use research within specific design projects.

Future work will investigate opportunities in the maritime context for HF/E and HCD integration. For one, it will assess design project challenges and how HCD principles can be used as a potential solution. In contrast, it will explore the barriers and constraints in current HCD applications, and evaluate their origins in order to understand if and how they can be overcome, and if and how the proposed benefits can be realized in practice and future generations of seafarers can take part in marine design. This should require taking an in-depth look at current processes and how HCD can be integrated, with the example of E-navigation applications. Within E-navigation applications, it would be interesting to test the standardization of onboard systems as a solution for usability issues experienced onboard ships today, through HCD and Software Quality Assurance Guidelines for E-navigation.

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