Snorre Hjelseth

Simulation and design

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Abstract

In this thesis, I investigate the use of simulation, game engines and real-time interaction in user-centred design for the maritime sector. In this sector, users are involved in complex safety critical operations carried out in very challenging and shifting conditions. This is a major challenge for workers and currently human failure is the main cause of maritime accidents.

To help relieve such problems, product and interaction design have traditionally applied a user-centred design approach. However, in the maritime sector, user-centred design approaches has only been used to a very limited extent. I raise two major challenges for applying user-centred design in maritime design. First, it is very difficult to account for the complexity of maritime context in on-shore design situations. Second, it is difficult for designers to gain access to user context as part of the design process.

Due to these challenges, I argue there is need for new approaches to handle the holistic design process necessary to understand relations between existing events and future scenarios in terms of context, operation, tasks, technology, systems and users. I propose that applying computer-simulated scenarios in user-centred design can help relieve the aforementioned problems and so position user-centred design in a more central role regarding innovation in the maritime sector.

Through several case studies of design projects in the maritime industry, I have researched the role of user-centred design in maritime innovation and have uncovered challenges that need to be addressed. In adopting a research by design approach, I have been able to implement new approaches using simulation in collaborative design sessions at the front end of innovation dealing with ideas and concepts. Game engines as both a platform and a meditational tool have been explored and analysed so as to represent, model and simulate boundary objects in real-time.

I propose that there is a need to approach user-centred design in the maritime sector according to a ‘design in use time’ approach rather than a ‘design before use time’ approach. To do so I have used concepts and taxonomies from simulation in the natural and social sciences to develop a design-centred view on simulation. Such a *design-centred view on simulation* seeks to create a design space for exploration intended to reveal the issues, challenges, solutions and possibilities related to a particular context of use. I introduce two new models to support a design-centred view on simulations. *The Contextual Simulation Space Model* and the *Contextual Simulation Process Model.* These models build on a combination of simulation, gamification and real-time interaction to describe context-related events and scenarios useable in collaborative design sessions with users and actors.

I suggest that, when used as a simulation tool, the game engine functions as a platform connecting the different types of media used to construct scenarios. In addition, game engines offers game-related functions that also can be used in by designers to render user experiences. The use of game engine driven scenarios may help designers to work with complexity on multiple levels, which addresses the web of connections between context, operations, tasks, systems, technology and users. My analysis shows that we can use simulation to model the actions and behaviours of users together with the evolution of systems as a time-based method to immerse the designer 'in use time'. I argue time element is vital when designing for safety and critical operations, and I show how simulation and gamification using real-time interaction can be used to manipulate time in the scenarios I have developed. Overall, the research can lead to a better understanding of simulation in user-centred design as well as how it can be developed further to address the safety and critical matters in other domains.

Part 1

Chapter 1: Introduction

In recent years industrial and interaction design practice has had increased influence in the maritime sector. These disciplines utilise user-centred design (UCD) processes to perform field studies, user participation facilitation, collaborative design sessions, scenario development and concept development. Designing for the maritime domain is a challenge for industrial and interaction design practices since products and systems need to be developed in multidisciplinary settings. These are also settings permeated with risk and safety critical issues that are related to complex tasks and operations. These challenges become even more difficult when designers have limited access to the activities, demands and needs of users and contexts of work at sea. To meet such challenges there is a need to establish new design processes, tools and methods that facilitate integration of user knowledge in interdisciplinary design teams designing for complex maritime work.

In this thesis I examine how designers may use simulation and game engines to inform UCD processes for safety critical situations in the offshore shipping industry. I present 6 case studies from maritime innovation projects where I have explored the use of simulated user scenarios via the application of a design-centred perspective on simulation. I have developed this approach by using game design for scenario development and real-time game and simulation functionality for collaborative reflection-in-action. Based on my research, I propose integrating game technology when designing within the context of safety critical situations in the maritime domain.

The maritime industry has a long tradition of conducting technology-driven innovation processes that are based on a technology push culture with little attention to usability. Although this approach has been successfully carried out for many years in the Norwegian maritime industry, recent studies suggest that such an approach has limitations. For instance, Rothblum et al. show that human failure, caused by a combination of organization, technology and the environment's incompatibility with human performance, is by far the largest contributor to maritime accidents (Rothblum, 2000; Bjørneseth et al., 2008; Michelle et al., 2002). These insights have led to a general acknowledgement in maritime research, among regulatory authorities and within the industry, that there is an growing need for UCD in maritime innovation strategy processes.

A major barrier for UCD in the maritime sector is the lack of connection between maritime contexts at sea and the designer on-shore (Lurås, 2014; Mills, 2006). Since designers and researchers have limited access to daily maritime operations, it is difficult to develop a holistic understanding of the relations between contexts, operations, tasks, systems and users. Added to the challenge is the complex interdisciplinary collaborative practice required to develop maritime innovations where practitioners and users from multiple fields need to be efficiently involved in development processes of conceptualisation. Further, maritime operations are carried out by a team of people who run multiple advanced systems simultaneously in order to carry out safe and efficient operations. It is difficult to integrate such complexity into on-shore design processes and for them to be effective back in contexts of actual maritime operations.

Currently, no design tools exist that specifically support UCD for complex maritime operations. However, attention is increasingly being given to the use of computer simulation to support development in the maritime domain. In my work I have explored how computer simulation (hereafter referred to as simulation) might be used as a tool in UCD. Simulation uses computation to evolve a system over time. Bradley et al. described it as: 'driving a model of a system with suitable inputs and observing the corresponding outputs' (Bradley el al., 1987:11). Design simulations may be used for testing phenomena and optimizing systems for and with users. There exist many simulation tools and techniques that allow simulation of maritime operations, and there are many cases where simulators have been used in maritime design. However, they are mainly used in engineering where the goal is to test construction in a development process, and they are only accessible to designers to a limited degree. To be able to use simulation in

UCD, other approaches are needed where simulation tools and techniques focus more on exploration of design problems in future user context.

Simulation tools refer to the simulation software that calculates mathematical formulas that have been made to model a real world situation. This calculation is referred to as running the simulation model. Computer simulation has been used and developed in most domains in the sciences (Winsberg, 2010) and is part of everyday engineering practice. Simulation is often used when a real system cannot be engaged. This might be because the system does not exist, is too dangerous or is inaccessible. Simulation is also used to model and study chaotic, complex and large-scale phenomena in detail (Banks, 2011). This ability to use computers to calculate and evolve systems has changed the way the world approaches problems. The word simulation is used in many different ways and relations. It can be grouped into areas, applications and techniques. Because the world of simulations is so diverse it can be very difficult to define what is and what is not a simulation. Some argue that all humans perceive the real world as a simulation and that we are living in one (Bostrom, 2003). Films like *The Matrix* have used such theory to create a narrative where humans can exist in several worlds. Some argue that everything on a computer is a simulation because it simulates binary code into readable information.

To frame UCD in a simulation perspective I have created the concept of a *design-centred view on simulation*, I draw on simulation taxonomy from the natural and social sciences. However, I focus instead on an explorative research approach where I test simulation techniques and applications in different design processes and settings, not science or engineering ones and their models.

Simulation tools require advanced knowledge to operate them and are often not necessarily compatible with UCD processes. Game engines represent a promising genre of simulation tools that might meet such challenges. These have seldom been explored in design research. A game engine is a piece of software used for the creation of computer game experiences. It normally consists of a 3D engine, software tools and a game editor facilitating efficient content generation. Game engines enable the use of real-time and simulation technology in virtual environments. This opens up new possibilities for designing within complex systems and contexts and understanding maritime operation and user tasks over time. Game engines allow designers to combine several types of media such as 3D models, animations, audio, video, pictures and numerical data visualisations into a simulated model displayed by the 3D engine with real-time interaction capabilities. Here I refer to media as a unit that holds some type of information that may have different materiality, shape or state. The game engine allows for the collection of several types of media in the same simulated time and space.

In this thesis I take up how we can use game engine simulations as tools in collaborative design processes for concept development in the *Fuzzy Front End* (FFE) (Koen, 2004) of maritime innovation. The FFE refers to the first stage in the design process where the project direction might not have been set and the process diverges in different directions in order to explore problems and solutions. My competence lies within industrial design and UCD with a focus on project management, ergonomics, aesthetics, form creation, visualisation and 3D design, construction and interaction. Although I have limited experience in computer simulation coding, my design competence has enabled me to approach research on simulation from the application perspective of how to better carry out collaborative UCD processes in the context of maritime operations.

I have used game engines to shape simulated scenarios in support of UCD in real-world safety and risk critical maritime operation design projects. I have done so through performing several simulation-supported case studies of design processes in collaborative sessions with maritime actors and users. I have used research by design (e.g. Morrison and Sevaldson, 2010) as a method to research design processes through practice and engaged in a dynamic dialogical interplay between practice and theory in making and critiquing. Further, UCD has been used to position the research in a design setting that has been informed by play and game design in order to frame methodological aspects concerning scenarios of use and potential application. Scenarios refer to a series of actions and events that can be generalised from past or possible future events (Bødker & Iversen, 2002). Participatory Design (PD) theory has been taken up when arguing for the collaborative approaches in the design processes. These have included users and actors in collaborative design sessions where they actively take part of design through scenario exploration and suggesting alternatives to designs. PD can be defined as:

> A process of investigating, understanding, reflecting upon, establishing, developing and supporting mutual learning between multiple participants in collective `reflection-in-action´. The participants typically undertake two principal roles of users and designers where the designers strive to learn the realities of the users´ situation while the users strive to articulate their desired aims and learn appropriate technological means to obtain them. (Simonsen & Robertson, 2012:2)

Through applied design work and critical interpretation and analysis, I have developed new approaches on simulating maritime scenarios and novel ways for handling complex tasks when designing for the maritime sector. This thesis by compilation includes four related refereed research publications and an overarching exegesis (or 'kappe'). In this exegesis, I further present three concepts, simulation, gamification and real time in relation to UCD based on the theoretical frameworks and research methods The concepts are used to inform a new design centred model – a *Contextual Simulation Process Model* - that connects modelling and simulation in game engines to the physical environment and the design space between designer, actors and users. All in all, I have found that game engine driven simulations offer a fresh approach for understanding maritime sector users in their work environment, not only focusing on their tasks, but also their internal picture of their role, risks, safety and culture.

THE MARITIME SECTOR

My research is situated in the maritime sector that can be grouped into shipping, offshore and fishing industries. These industries often overlap when it comes to the use of services, systems, technology and competence because they are all connected within the maritime setting. In my research I have worked with shipping and offshore design challenges such as crisis management in the Oslo fjord (shipping), seismic operations, dynamic positioning in the polar areas (offshore) and helicopter deck design (offshore and shipping).

The maritime industry is of strategic interest for Norway, a recognised international figure in the sector. The Norwegian Ministry of Trade and Industry has published a strategy document for future maritime growth (Handelsdepartementet, 2007) that aims to position Norway as a global leader for maritime innovation and environmental solutions. The main drivers for such development are globalization, an environmental friendly maritime industry, maritime proficiency, maritime R&D and local shipping.

Jenssen (2003; 2004) has conducted research on innovation in Norwegian shipping. For the Norwegian shipping industry to compete with industry in low-cost countries, innovation has become a crucial part of differentiation. Jenssen (2003:94) questions 'how the shipping industry can be more innovative in order to uphold and strengthen its competitive advantages' and concludes that there are opportunities for better communication and collaboration between maritime companies. What is not discussed is how design may be active in such development no their application in addressing key matters of safety.

With human failure as one of the major causes for accidents at sea, it is critical that designers are able to handle user-relations as part of their design material to explore and reveal critical aspects for safety and innovation. This is a problem since the maritime domain traditionally has focused on new technology as their main area of innovation and profit. User aspects have often been seen as a necessity for fulfilling safety requirements rather than a starting point for new innovation. Consequently, even as increased attention is placed on UCD, core actors and clusters of expertise and achievement in the maritime sector might not have the right competence, skills, methods and tools to incorporate it as an innovative strategy.

Linder's (2008) pilot study on the offshore ship industry shows that industrial designers lack a tradition in the maritime clusters and thereby lack status and power within the industry. Only a few companies in the study had used industrial designers as part of their innovation process and in many cases the interaction between the designer and the company had failed. Failure occurred because of cultural differences between designers and cluster actors. The study shows that there is a mutual lack of motivation and interest for collaboration and lack of knowledge and respect for counterparts and design processes. Opportunities that are presented by industrial designers are often turned down because of the complexity of working with multiple actors within a maritime cluster. There is also a problem that different collaborating actors have different strategies for innovation. Linder points out that major potential exit to enhance products from the user point of view in the maritime sector.

User needs and problems should be addressed and related to maritime systems and contexts. This means that design methods and tools must be able to mediate information about the system and context. This is a challenge when designers have limited access to the maritime context where user studies, information gathering and testing take place (Lurås & Mainsah, 2013). Earlier research (Grech, Horberry, & Smith, 2002; Kristiansen & Nordby, 2013) in the maritime sector has shown the implications using surveys to capture complex user-related operations at sea. Hukkelås, principal engineer for maritime operations at Kongsberg Maritime representing one of the main maritime suppliers, argues:

> The UCD approach ensures a clear focus on the user and the tasks that he is to perform from the very early design phases, which will undoubtedly lead to improvements from the user's point of view – this will affect effectiveness, efficiency and user satisfaction. UCD is not a new concept. It is used across many industries, but to a very limited degree to date in the design of ship systems. One of the major challenges when utilising UCD processes in the maritime domain is the fact that 'the work' is done at sea, which limits the availability of the work domain for designers. Also, since work in the maritime

> sector is safety-related, the testing of prototypes is very difficult to be done aboard ships. (Hukkelås, 2013)

When users work with complex systems in safety and risk critical contexts that are not easily accessible for designers, understanding minor tasks might become a huge challenge. Human factors research that has been applied to critical work environments has traditionally focused on task analysis and situation awareness (e.g. Flach, 1995). These methods are important to understand users, but it can be a challenge to use them as input for new designs since they are not primarily developed to support product innovation. Design in the maritime sector demands a constant cycle between conceptualisation and understanding users and systems.

It is critical that designers also perform field research to understand contexts of work and use. This is because they are then able to directly relate observations and interviews to design problems and issues that can be understood only through the process of designing informed by contexts of use and use in context (Lurås & Nordby, 2014).

DESIGN PERSPECTIVE TOWARDS THE MARITIME SECTOR

Simon defines design as a process of 'changing existing situations into preferred ones' (Simon, 1969). In my work I follow a UCD perspective that focuses on all aspects related to human needs and what surrounds it (Gould & Lewis, 1985; Norman & Draper, 1986; Keinonen, 2010). Design problems related to UCD are often considered as ill-defined (Lawson, 2006; Lawson & Dorst, 2009) or wicked (Rittel et al., 1973) because user needs often are challenging to define and the act of creating a design often has several unknown factors. This means that UCD problems require analytical approaches, qualitative work and hands-on design interventions. Such design rich processes can be described as *reflection in action* and include the use of *framing* and *re-framing* problem techniques (Schön, 1983).

The *design space* (Gries, 2010) created as a mental model during design processes may be understood as a structure of information and ideas that defines boundaries in a space that might have several axis and dimensions that coexist simultaneously. Such a space can be seen as a converging and diverging structure available for exploring and analysing new paths of problems and solutions (Lawson, 2006). A designer enacts parts of this space through artefacts and boundary objects (Star, 1989; 2010) to communicate the mental model and share the design space with other designers, user or actors. Here, boundary object refers to the contextual object that facilitates the discursive process in a collaborative design setting.

One of the core competences of designers is to simplify and organise complexity in order to handle design problems. Several methods, such as reframing (Schön, 1983) GIGA-mapping (Sevaldson, 2013) and user scenarios (e.g., Buur & Larsen, 2010), have been developed to handle levels of complexity and related challenges in the meeting of humans and systems. Still, there is a need for new design tools and methods suited to new markets and contexts, such as perceiving and tackling matters of risk, response and reflection at sea. One way forward is to adopt the design material and processes of flexibility of computational tools such as simulation in order to manage complexity in design processes.

A user-centred view on design is increasingly important in maritime innovation. In an industry where technology has been the main approach to innovation, I have seen a change towards user needs as the starting point for innovation. However, I have found that designers lack the tools and methods to handle maritime complexity. Going forward it is critical that designers extend their ability to understand users, systems and operations in maritime contexts and to bring their own expertise and situated design practice to bear on conceptual work at the fuzzy front end of innovation that itself needs to be oriented towards actual contexts of use and development.

SCENARIO SIMULATION IN MARITIME USER-CENTRED DESIGN

It is a challenge to apply simulation to UCD because the problem solving approach is fundamentally different in UCD than other disciplines, e.g. mechanical engineering, biology or computer science. There exist some examples of simulator use in design, but they are mostly used as *human-in-the-loop* integrations (Narayanan & Kidambi, 2011) aimed at testing or evaluating design solutions, even though they involve users in their processes. Some work in simulation is also used for conceptualisation and focus on user experiences but mainly as a process for evaluating user actions (Kuutti et al., 2001; Kumar et al. 2011). UCD and simulation is also being studied in *Virtual Reality* (VR) research, but this research tends to focus on interface development to create immersive experiences (Tideman et al., 2008; Manninen 2000; Thalen & Voort, 2012).

Simulation in the maritime sector deals mostly with well-defined challenges like hydrodynamics, stress tests and electrical systems. However, some tests simulating user scenarios and operations have been done when installing of new lifeboat facilities on the *Statoil Visund* oil platform (Maslin, 2013). It appeared that there was a space for design centred views on simulation to be developed further in the maritime sector and that game engines would offer some means to this end.

RESEARCH AIMS AND QUESTIONS

The objective of this work is to investigate the use of computer visualisation and simulation to explore existing events and future scenarios of maritime operations as means for conceptualisation and collaboration in design. My main research aim is:

> *1. How can new approaches through simulation be developed to answer the challenges of UCD in the front end of maritime innovation?*

I also address the following sub questions:

> *1a. How can simulation as a tool and process be explained in UCD?*
>
> *1b. In what ways can gamification improve UCD processes?*
>
> *1c. How can the use of simulation tools influence the understanding and manipulation of time in UCD processes?*
>
> *1d. What might a model that connects the relations between UCD, simulation, gamification and time be conceptualised as being?*

METHODS AND THEORETICAL FRAMEWORKS

The research described in this thesis is related to real world processes and challenges from design practice. In other words, it is necessary to conduct research on practice through practice. Briefly, research by design offers the possibility to research design through design practice. This approach is closely related to action research and participatory action research through case studies that focus on inquiry through practice in the real world. Drawing on these routes to inquiry, and their contextual and reflexive qualities, has enabled me to work simultaneously as a designer and researcher. This dynamic method has been applied in all levels of my design work from planning and performing collaborative design sessions, exploring and testing visualization and simulation tools and techniques, and in the process of making boundary objects and modelling scenarios. Participatory design and co-design have been used to relate my research to interdisciplinary aspects that are described as one of the challenges of maritime innovation. In the exegesis I bring in new aspects not described in published publications such as a *design-centred view on simulation* that builds on aspects of gamification and real-time. I also introduce play and game design to define concepts between collaboration, UCD and simulation.

THE CONTEXTUAL SIMULATION MODELS

The main contribution in this thesis is the development through case based inquiry of a *Contextual Simulation Process Model* and *Contextual Simulation Space Model* that combines real time, simulation and gamification in a design setting. The contextual simulation process has been developed through action research and research by design, using participatory and co-design in collaborative design sessions with users and actors. The contextual simulation map offers a framework for simulation supported conceptualisation in UCD, which focuses on users communicating in context or using objects to perform tasks. Situations can be abstracted into more general scenarios where specific events are described. The contextual simulation process models these scenarios based on how they ought to be presented in a real world setting, including its contextual relations and time. The simulation can be modelled in several different ways to support the scenarios. Gamification (Deterding et al., 2011) further offers the tools, technology and plasticity that enable the scenarios to be created and explored. Further, reflection-in-action is part of a different time and space and it is important to link these two together in real time. The contextual simulation space and process positions these elements in a system that can be used to facilitate design processes to deal with issues of complexity that can be especially found in the maritime sector.

STRUCTRE OF THESIS

The thesis is structured in two parts. The first part, Chapters 1 to 4, represents the extended analysis and contribution built on the published publications. The second part consists of four publications published at conferences and in journals. Together these two parts constitute the overall thesis by compilation.

Part 1: Exegesis

This part of the thesis is divided into 4 chapters. *Chapter 1: Introduction* introduces the area of research, the main research problems and a summary of the research publications. *Chapter 2: Research context* explains the research relations and activities, design perspectives, simulation theory and role-play and game design frameworks. *Chapter 3: Research methods and design techniques* describes and justifies the research method and presents empirical material created through case studies. *Chapter 4: Reflecting on simulation in design* discusses three concepts based on the initial research findings and presents the *Contextual Simulation* models.

Part 2: Publications

I include three conference publications and one journal publication as part of the thesis. The publications include work that investigates the challenges of complexity related to emerging contexts, user involvement, collaboration and maritime design. This covers material that investigates and explores 3D visualisation in collaborative design sessions, development of immersive collaborative design-lab tools, the use of simulation and the use of game-engine driven scenarios for maritime design. The publications are presented in the chronological order that reveals the explorative approaches used in the research. All the publications have been peer reviewed. I now provide a brief summary and orientation to each of these publications.

Publication 1: 3D-visualizations as a means for engaging users and actors as co-designers in the fuzzy front-end of product development

Hjelseth, S. (2011). 3D-visualizations as a means for engaging users and actors as co-designers in the fuzzy front-end of product development. In *Proceedings of the 4th World Conference on Design Research: Diversity and unity* (pp. 649–652). Delft: TU Delft.

In this publication I took up the challenges of engaging users and actors in the fuzzy front-end of maritime innovation to develop a shared understanding of ideas and concepts and to act as co-designers in developing future scenarios.

I investigated the challenges by exploring the role of realistic 3D visualisations in the fuzzy front-end of product development process. Throughout a design process I used 3D models to iterate design ideas and concepts exploiting the layer structure functionalities of a 3D visualisation tool which enabled fast changes in the presented visualisations. This enabled me to use 3D visualisation as tool and means in a collaborative and participatory process to integrate users' and actors' competences in the design process.

I studied the design process and used qualitative interviews to investigate how the design process participants experienced the use and role of visualised scenarios. I analysed the results by comparing my design process experience and the interview data. I also compared the differences between the use of physical scale models, 2D drawings and 3D visualisations.

I found that a diverse group of actors and users representing different practices were able to create a better and shared understanding of the design ideas and concepts when using the 3D visualisations. Because of the 3D visualisation realism, the participants became more enthusiastic when they got their own ideas visualised. I also found that the initial 3D models used in the front end of the design process could be iterated and re-used on other levels such as decision-making, external marketing and project involvement.

Based on this experience, I found that using 3D visualisations had limitations in its ability to allow transformation of the models during collaborative design sessions.

Publication 2: Innovative conceptualisation through sense stimulation in co-lab development

Capjon, J., Hjelseth, S. (2012). Innovative conceptualisation through sense stimulation in co-lab development. In Heisig, P. and Clarkson, P.J (Eds.), *Proceedings of the 2nd International Conference on Modelling and Management Engineering Processes* (pp. 61-74). UK: University of Cambridge.

In this publication Prof. Jan Capjon and I questioned how new visualisation and interaction technology could be integrated in the design of a collaborative design environment.

We described the design principles and reflective design process behind the realisation of our collaborative design-lab called SimSam, which builds on the *Plant of Collaborative Conceptualisation* (Capjon, 2003) design process model. Using state-of-art technology and human preconditions we described how collaboration and new patterns for conceptualisation in an innovation framing could be used to create new methods and tools for design. We evaluated different types of multi-screen settings, information organisation on display, collaborative display interaction and drawing tools through multi-touch displays and use of game engines as visualisation tools.

In the publications we described tools and methods created for the collaborative design- lab setting. We also did two case studies in the design-lab where some of our process and tool concepts were implemented.

We found that new approaches such as *perception maps* and integrations between multiple screens and touch screen technology could be developed based our initial design process model about conceptualization and collaboration. Perception maps were based on using a structured diagram to compare design concepts addressing the same design problem.

Through the process of exploring new visualisation technology, I also found several simulation techniques that could support new approaches in collaborative design sessions. This led me to investigate the use of game engines as simulation and visualisation tool in subsequent studies.

Publication 3: Emerging tools for conceptual design: the use of game engines to design future user scenarios in the fuzzy front end of maritime innovation

Hjelseth, S. (2013). Emerging tools for conceptual design: the use of game engines to design future user scenarios in the fuzzy front end of maritime innovation. In *Proceedings 27th European Conference on Modelling and Simulation (*pp. 170-176). Ålesund: European Council for Modeling and Simulation.

In this publications I questioned how it was possible to understand and analyse complex user scenarios in the maritime and offshore industry and how we could use game engines to simulate such scenarios.

The paper presented a case study where I used a game engine as a design tool to create dynamic user scenario environments facilitating a design process. The goal of the research was to see if it was possible to integrate realistic real-time simulations with user input in the conceptualization of innovations. Using data collection and a field study conducted at an offshore operation, I studied some of the complexity in understanding user scenarios in interdisciplinary design groups.

The results showed that offshore operations often were very complex because several tasks and systems were simultaneously active during the same operation. It was a challenge for an interdisciplinary group of developers to create a holistic understanding of such a complex situation to support their design work.

I suggested the use of design thinking and user involvement in combination with simulation tools could create a platform for an iterative process to develop and explore complex user scenarios that drive conceptual innovation. Through using game engines to model scenarios described in the case study, I found that it was possible to do further research in the use of simulation, real time and game engines as design tools to address different types of design needs.

Publication 4: Design and computer simulated user scenarios: Exploring real-time 3D game engines and simulation in the maritime sector.

Hjelseth, S.,Morrison, A., & Nordby, K. (2015). Design and computer simulated user scenarios: Exploring real-time 3D game engines and simulation in the maritime sector. International Journal of Design, 9(3), 63-75.

We address the challenges of using UCD in maritime innovation that relates to the complexity of contextual related systems and operations that is safety and risk critical. To do so we investigated the use of game engines as a design tool to conceptualise and simulate possible future user scenarios in collaborate design sessions in the maritime sector.

We present three case studies were we tested different simulation techniques in collaborative design sessions. In order to relate action research to the design and design process we applied research by design as a research framework.

The user cases where used to discuss the relations between simulation in UCD and maritime design complexity in safety and risk critical operations. Further, we presented key aspects on the use of game engine tools and simulation of scenarios in design. By using the simulation functionality found in a game engine, we explored its ability to mimic real-world conditions of contexts, systems and behaviors over time.

We argued that game engine simulation tools and techniques, allowed us to approach challenges in maritime design processes that would have been impossible with other design scenario and storytelling methods and tools.

These publications show how I, throughout my project, have moved from static 3D visualisations to dynamic real-time simulations of entire environments in order to facilitate design processes. A key aspect has been to engage with both design and engineering research communities to understand how new design tools and processes can be applied to maritime innovation. A close connection and collaboration with maritime companies has been very important for providing real-world boundary conditions for my case studies.

Connections between publications and the exegesis

This exegesis builds on the research included in these four publications. Each publication describes different perspectives to simulation in design. Together they show my exploratory process towards understanding and developing simulation for design. Conceptualisation in innovation, scenarios, collaboration and a multidisciplinary approach through UCD in the maritime sector can be found in all the publications and help creates a core theoretical framework for the thesis.

The process of the research has also been important in building this framework. Because of the enthusiastic reaction of the users involved in the first case study, my research shifted toward finding new processes and tools to facilitate UCD design processes. However, some of the design issues and challenges were already identified in the first publication, but became more evident in subsequent research involving multiple users and stakeholders in commercial settings.

This thesis' main contribution, the *Contextual Simulation Space Model* and *Contextual Simulation Process Model*, was based upon issues of scale when visualising scenarios, which I brought up in this first publication. This is especially relevant considering what I describe as micro and macro levels where game engines provide the possibility of zooming in and out of very detailed things and macro perspectives on maritime contexts together with users and actors. The micro and macro visualisation technique was also used during field studies using video recordings of an offshore operation in the process of designing an offshore simulator. Several cameras recorded the operation from several perspectives, which allowed detailed tasks to be observed in combination with the holistic operation picture.

I discovered realistic visualisation techniques were highly relevant area for maritime innovation processes involving UCD because of the complexities and challenges of designing for users in the maritime sector. However, the detailed and realistic visualisations led to a very fixed setting when used as boundary object for collaboration since they could not be changed in real time. To support iterative concept development, hand sketching was used with the support of detailed and realistic 3D visualisation during collaborative design sessions.

Game industry technology has developed tremendously during my period as PhD student and has been part of changing the research direction. The second publication reports on our research on new visualisation technologies facilitating design. This publication brings forward simulation as method and tool to facilitate multidisciplinary collaboration for conceptualisation. We found that existing models for conceptualisation and collaboration can be reshaped through the use of new technology. I later used this approach to shape the contextual simulation models by combining multidisciplinary approaches to conceptualisation. We asked, 'How shall scenarios be organised in terms of operational visualisation characteristics and tooling?' In the case presented, we solved this by using multiple screen solutions, and tested a non-interactive dummy version of this during the experimental, collaborative design session.

The layered structure of real-time game engines I used to build and edit a virtual environment allows for swift shifting between several scenarios and combining elements from existing scenarios into new scenarios. This function resulted in a much more dynamic use of the scenario visualisation as a boundary object, which allowed not only a dialogue between collaborative actors using a fixed artefact, but also an evolving dialogue through the visualisation that changed throughout the design session. It offered a more sketch-like experience in using 3D models as boundary objects in design. This plasticity of real-time game engines makes up one of the core functions in the contextual simulation models.

Publication 3 goes further into the use of scenarios to facilitate conceptualisation in collaborative design sessions. The publication introduces how computer simulation can allow scenarios to evolve together with maritime actors. In the publication I bring up the relations toward simulators and VR research that documents that scenario simulations can improve information quality and quantity from end-user feedback that mainly focus on usability issues (Thalen, 2011). This is one of the areas that distinguishes my research from similar research using virtual environments in design processes which focus on usability testing through VR interfaces. In my approach the actors and users co-explore scenarios where the designer facilitates the interaction with the scenario as a discursive collaborative process without the focus on VR interface interaction.

In publication 4 I investigate the use of simulation in scenario exploration and develop knowledge on how the different simulation functions can be used in a collaborative design setting. It reports on different ways of simulating behaviours of objects, systems and humans both in direct and indirect participation with larger groups of stakeholders and in single actor design sessions. I bring together the outline that informs this exegesis through connecting design, simulation theory and game tools in the maritime context. It becomes evident that the contextual relations that are modelled and become central to the scenarios used as boundary objects can materialise and mediate a combination of design factors on the same platform such as tasks, environment, operations, objects, users, time and systems. I argue this is impossible with traditional design methods and tools.

S U M M A R Y

Through this thesis and four publications I have investigated challenges and issues related to UCD in maritime innovation processes. The challenges are based on how to approach maritime design characterised by a complex network and relations between users, systems, and tasks in risk and safety critical contexts. I believe that designers need new tools and methods for such challenging and demanding design tasks. My main contribution is that simulation can be used for exploring and evolving user scenarios using game engines as a collaborative platform that can mediate the relations between contexts, systems and users.

Through simulation software experimentation, case studies on industrial design projects and interviews, I have analysed different maritime design approaches. I have learned that computational simulation techniques have some unique functions in UCD that enable designers to explore with users in context. Computational simulation allows multidisciplinary design actors to connect data and media to shape holistic design concepts. The time aspect in simulations becomes a factor for setting the boundary conditions for integration, which helps designers focus on the time aspects in their design. Based on these findings, I have shaped a theoretical concept on simulation that frame solutions for collaboration and scenarios in UCD. This involved creating a design-centred view on simulation, implementing play and game design for scenario development and using real-time functionality for collaborative reflection-in-action in the maritime sector. I have proposed elaborated models from this work and it is a key result of the overall inquiry.

Chapter 2: Research Context

To approach visualisation and simulation in design, a multidisciplinary approach has been adopted that includes research fields such as modelling and simulation, computer supported cooperative work (CSCW), participatory design, virtual reality (VR), human factors, E-learning, play theory and game design. Of these research areas, the focus has been on simulation and its relation to design as the primary research framework. The other presented research areas serve as scaffolding for the focus on simulation. In the following sections, the context of the research and its background in practice are described.

THE PROJECT'S RESEARCH RELATIONS AND ACTIVITIES

This research has been part of the research activities at Buskerud and Vestfold University College (HBV) and The Oslo School of Architecture and Design (AHO). The relations have allowed for drawing on expertise from other ongoing design-related research projects and communities, which has been important for this work because it involved collaboration and multidisciplinary practice in marine design. At HBV at the Department of Maritime Technology, Management and Innovation, I have been part of developing the SimSam-lab. The SimSam-lab is a design and simulation laboratory that facilitates processes using design conceptualisation techniques and collaboration theories in combination with state-of-the-art technology to shape new tools, processes and methods. Professor Jan Capjon and I co-designed the lab as part of my PhD research, and it got me going on the track towards exploring visualisation and simulation in maritime innovation. Currently, the lab is used for simulator training courses and research on simulator use and technology. I have used SimSam for several collaborative design sessions with industry partners to research design tools and processes. Twenty-eight different companies have participated in seven innovation and design projects, some of which are presented as cases in this thesis, using the SimSam-lab.

Academic research collaboration partners

It has been important for this study to have other maritime design researchers discuss the opportunities and challenges in the maritime design processes. At AHO, I have had close contact with the Ocean Industry Concept-lab, which has completed extensive projects on ship bridge designs with the Ulstein Group in Norway (Figure 1). We have collaborated on a case study based on a scenario of dynamic positioning operators in platform supply vessels (PSV).

The Ocean Industry Concept-lab has published several journals, magazines and conference articles based on their research, such as 'Field studies informing ship's bridge design' (Lurås & Nordby, 2014), 'Reaching hard-to-reach users using online media to get a glimpse of work in marine contexts' (Lurås, & Mainsah, 2013), 'Towards a Design Simulator for Offshore Ship Bridges' (Kristiansen & Nordby, 2013), 'Conceptual design as a driver for innovation in offshore ship bridge development' (Kristiansen, 2014), 'Systems Oriented Design in Maritime Design' (Sevaldson at el., 2012), 'Using online image sharing of ship bridges in maritime research and development' (Nordby at el,. 2012) and 'A different systems approach to designing for sensemaking on the vessel bridge' (Lurås, 2012).

Figure 1. Picture of a future ship bridge produced in the Ulstein Bridge Concept research project. The bridge concept shows how focus on the interaction between user, ship and operation is materialised through new concepts on interaction and technology. The concept also brings in a new mind-set on the bridge, which must be seen as a holistic interface and not as separate modules as is the case on most ship bridges today.

PERSPECTIVES ON DESIGN

This study is in the field of industrial design and is seen as a subfield of design. Designers deal with complexities on multiple levels that can be described in a hierarchy of components, products, systems and community in which design addresses a web of connections between people, activities, objects, technology and settings (Jones, 1970). Designing can be described as the process of '…changing existing situations in to preferred ones' (Simon, 1996:111). Design is also closely connected to the use of interdisciplinary collaboration tools and interacts through artefacts and representations of processes when organising the work (Perry & Sanderson 1998).

Industrial design has several important functions in maritime innovation processes, such as the first stages of creating visions and the development of ideas for conceptualization, prototyping, testing, development, manufacturing and marketing. During these processes, industrial designers focus on usability, aesthetics, functionality, form, branding and all aspects related to human experiences. Industrial designers draw on a wide range of fields that are related to several other areas, such as architecture, ergonomics, human factors, engineering, human computer interaction, graphic design, marketing and manufacturing.

Several definitions for industrial design have been suggested, but no definition has been universally accepted, most likely due to the wide perspective of the different functions of its practitioners (Gemser & Leenders, 2001). For instance, product design, interaction design and service design may all be seen as subcategories of industrial design with different and often overlapping perspectives. Industrial design in the maritime sector is directly connected to and sometimes overlaps design in engineering disciplines. For this work, I chose to define industrial design as the process of designing innovative user experiences based on user needs.

The Fuzzy Front End (FFE) of innovation (Koen at el., 2002; Koen 2001) is placed in the very beginning of the innovation process, such as in the *Stage Gate Process* (Cooper, 2001), which describes different stages in new product development. The FFE is the stage in which goals and problems are not well-defined and explorations and concepts are created. During this stage, radical innovation strategies that can be explained as 'the result of a vision of a possible future' (Verganti, 2003:38) are also most likely created. This means that radical innovation does base itself on incremental pulls from the market, rather it looks beyond the product of tomorrow in several steps into the future. The opposite innovation strategy of radical innovation is incremental innovation, which can be explained as a process of optimising existing designs. Radical innovation strategies in design can focus on creating new needs using socio-cultural meanings through design (Verganti, 2003).

Maritime innovation strategies are often based on incremental strategies that gradually improve specifications and performance through technology push and market demand. This is a problem because human failure is by far the largest factor involved in marine accidents (Rothblum, 2000; Bjørneseth et al., 2008; Grech et al., 2002). The result of this can be seen on ship control bridges in which new equipment has been installed in combination with old systems to answer safety demands without redesigning the control panel layout. To overcome such problems, the AHO ship bridge design for Ulstein used a radical design strategy to design a new concept bridge based on design approaches such as interface integration, which uses knowledge about the user and user situations as reference points for every design decision. This results in a more radical design strategy that improves existing functions from a totally new perspective, rather than optimising the existing design using an incremental strategy.

User-centred design

Maritime design processes are conservative, and it is difficult incorporate UCD, which is regarded as a fairly new approach in the maritime culture. This is a problem for the marine sector particularly since research shows that most accidents are caused by human errors. In this work, UCD is considered to be the core competence within industrial and interaction design that differentiates our design competence from other fields that deal with design in the maritime sector, such as engineering.

User-centred design (UCD) (Gould & Lewis, 1985; Norman & Draper, 1986) is defined by the Usability Professionals' Association (2014) as '… an approach to design that grounds the process in information about the people who will use the product. UCD processes focus on users through the planning, design and development of a product`. Keinonen (2010) describes several domains with slightly different approaches to UCD, which includes domains such as human factors (Sanders & McCormick, 1987) and ergonomics (Vavik & Øritsland, 1999), participatory design (Kensing & Blomberg, 1998; Sanders, 2002 Muller & Kuhn, 1993; Schuler & Namioka, 1993), design for user experience (Forlizzi, & Battarbee, 2004), service design (Erl, 2008), human-centred design (Gasson,2003; ISO 13407, 1999; ISO 9241-210, 2010) and usability engineering (ISO 9241-11, 1998; Nielsen, 1993).

My approach to UCD focuses on the relation between users' needs and users' experiences. Users' needs can be grouped into three areas: desire, instrumental and fundamental needs (Thomson, 2005). Desire needs are individual and personal needs based on preferences or feelings. Instrumental needs can be described as a need obtained through logical reasoning, and fundamental needs can be described as absolute needs, such as health and safety matters.

Providing the users' needs through a design does not necessarily create a design that focuses on the user experience satisfaction (Keinonen, 2010), and a narrow focus on experiences may not include more fundamental and instrumental needs. It is a difference between need and desire; however, desire is often used as an argument in UCD to claim a need. It is especially important in participatory and co-design to be aware of this through users and participation. When designing for user demand and critical safety environments, it is crucial to understand how the design influences users' needs. For a UCD approach, the designer will always ask how the design changes the users' situations and how it effects users' need through changing the system or contextual relations. For UCD, we therefore need approaches that not only focus solely on users' needs but also the relations between users, systems, operation and context.

Designing for users often requires a different approach than analytical thinking in which a problem can be analysed and a best solution can be directly applied, especially in the conceptualisation phase in the FFE of innovation in which needs and goals are often not well-defined. Such problems are referred to as *ill-defined* (Lawson, 2006; Lawson & Dorst, 2009), *wicked* or *unwieldy* (Rittel et al., 1973). Such problems require a solution-based strategy using trial and error (Capjon, 2004) in trying to understand the problem by solving it (Cross, 1982). Donald Schön (1983) describes this process as *reflection in action* using framing and re-framing to evolve the problem and solution space. Because this is a practice-based approach based on skills, it also requires a practice-based approach when learning design. In design, this process of reflection in action often happens through the use of prototypes, models, drawings, artefacts and boundary objects.

Boundary objects and critical artefacts

Materiality is the way physical artefacts represent themselves in the world, which is a crucial aspect of the representation for the artefact to be understood by participants in a collaboration process (Jacucci & Wagner, 2007). Virtual artefacts only exist in a virtual space and do not have the same sensual and tangible qualities as real-world materiality. I have used the boundary object to explain the immaterial material in my research and design processes.

A *boundary object* is defined as:

> ... objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. They may be abstract or concrete. They have different meanings in different social worlds, but their structure is common enough to more than one world to make them recognizable, a means of translation. The

> creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds. (Star & Griesemer, 1989:393)

The interesting aspect about boundary objects is the ability to exist in simultaneous states in which they are '…simultaneously concrete and abstract, specific and general, conventionalized and customized' (Star & Griesemer, 1989:408). This enables the boundary objects to shift between structured and ill-structured states in which the ill-structure may have unsolved factors (Star, 2010). An ill-structured state can trigger or encourage actors to resolve unknown factors with new data, approaches or perceptions.

Boundary objects is used as a representation in interdisciplinary discursive settings in which the boundary objects can represent different meanings based on social worlds but can easily be communicated. The concept is also about creating boundary objects in collaborative settings; however, in contrast to the participatory design, the boundary object does not necessarily involve design or design processes.

A 3D object environment that is virtual and is represented using scenarios as boundary objects is used in this study because they are made to communicate with actors and users. The boundary object used does not need to be the actual objective of the design, but it does involve the contextual relations in an explorative approach. Sometimes, these scenarios are created to provoke critical reflections, which are explained in the critical artefact methodology (Bowen, 2009). Critical artefacts are used to stimulate reflection, reaction and discussion among users. It can be seen as a way to provoke the users of the artefacts to position their argument in a discursive process. According to Bowen, 'critical artefacts have proved more useful as tools than direct questioning techniques; in particular as a way of enabling stakeholders to engage with novel situations and consequently engage in creative thinking about future possibilities' (2007:1).

Participatory design

Participatory design (PD) is an approach that is emerging from Scandinavia (Asaro, 2000) practiced by the work unions, and it is a part of Computer Supported Cooperative Work (CSCW) (Bannon, 1993). It includes users and actors in design processes to obtain more knowledge about users, situations and systems in design. PD includes political and democratic perspectives and enables user and actors to be involved when their work environment is being designed and changed (Kensing & Blomberg, 1998). Other aspects of PD focus on revealing users tacit knowledge and not only their explicit competence in design processes. Approaches such as "designing-by-doing" and “design-by-playing” are connected to “learning-by-doing” as inquiry into such knowledge (Ehn, 2008).

User involvement does not necessarily guarantee a successful design process with meaningful outputs. Bødker and Iversen (2002:11) argued that ‘user involvement is something that needs to be structured, facilitated and interpreted into directions for future design`. Part of this structure is design method and design processes that need to be looked at as learning artefacts and learning processes. In this thesis, I refer to such learning artefacts as boundary objects (Star & Griesemer, 1989).

PD is often performed in interdisciplinary collaborative design sessions in which several designers, actors and users are involved in a meeting constructed to do the design work. The philosophy of this is to create an atmosphere of knowledge sharing and to reach a shared understanding between the participants.

Co-design involves the collaborative aspects in PD. It includes concepts such as *collective creativity* (Sanders & Rim 2001) *and co-creation* (Sanders & Stappers, 2008) without necessarily involving the democratic aspects. Collective creativity can occur between two or more people in a collaborative setting in which new ideas are created through the combination of previously unrelated ideas. Co-creation is a process used in co-design and collective creativity in which two or more people are collaborating and collectively creating artefacts to facilitate the process.

Sanders has developed collaborative environments with co-design toolboxes that are used by users and actors to shape artefacts that reflect design problems (Binder at el., 2011). An example of a co-design process is sharing tacit knowledge by explaining it through materials instead of words. The concept is to not use the things shaped by actors and users as direct concepts or argumentation. The artefacts created and the discursive process while making them is a way of reflecting and analysing needs, challenges and problems as well as new ideas and solutions. This process is often iterative in the same design session, allowing the participants to frame and re-frame problems and solutions.

Methods such as scenario building and role-play are also possible to implement in participatory design sessions with users (Sanders et al., 2010). This means that the user can reflect on a future scenario using real-world experience from past situations. The use of scenarios and role-play in design can create surprising events that reveal problems or solutions (Dorst & Cross, 2001).

Through participatory design, we attempted to investigate how designs should be used by users by involving them in the design process. Ehn (2008) questioned whether or not PD and envisioning “use before use” is relevant to design since envisioned use is hardly the same as actual use. A strategy to overcome this challenge has been to not only design during a project (project time) but also during use (use time). This means that designing does not only occur through the creation of physical objects and things but also through use in context and in sociocultural settings. Through use or practice, *infrastructure* emerges, which is connected to activities and structures (Star, 1996). Infrastructures can be technical specifications or other mechanisms that are hidden in objects or cultures. Star stated that ‘infrastructure is `sunk` into, inside of, other structures, social arrangements and technologies’ (Star, 1996:113). Infrastructures focus more on the structure of the users’ situations rather than the object being designed and creates a new context for designing; however, these infrastructures can change from being an infrastructure to a topic dependent on a user (Star, 1999).

As a PD process, infrastructuring is described as a socio-material public thing that becomes the boundary object when designing during use (use time). These processes and strategies can be technical points of departure (protocols, formats, etc.), configuring (such as software platforms), components, design patterns and the relationship between design time and use time (Ehn, 2008). An example of how infrastructuring can be mediated is through machinima, which uses computer games to create game-based movies that are player-driven. Lowood (2008) described a case in which the industrial designer Alex Chan used the machinima technique to create The French Democracy (2005) film. The film uses narratives and scenarios that describe how minority groups in the African and Arab Parsian suburbs of Clichy-saus-Bois have been the victims of harassment and discrimination that led to the riots in October of 2005. The film was made public and was used as a public information medium outside regular media. Through the stories in the film, Chan was able to communicate the infrastructure of the underlying events that fuelled the riots.

In my research, I have used frameworks and methods from PD and co-design for facilitating the design processes in my case studies. Because the maritime context is often accessible to a limited degree, it is important to use methods and tools that can facilitate collaboration in design processes that utilise explicit, tacit and infrastructure knowledge from users and actors. Field studies using observations and interviews can supplement this learning process in designs for the maritime domain; however, it is not likely that critical risk situations will occur that may be a target of the design focus. Such events can be described through scenarios that can be co-created and co-explored using PD and co-design.

A *scenario* can be described as a series of actions and events that constitute a hypothetical future. Carroll (2000:46) referred to scenarios as the ‘stories about people and their activities’. Scenarios are more generalised in contrast to events that can be described as more specific in time, place and actions. Scenarios do often aim at specific series of instances in events that can be the target on a more abstract level. This makes it possible to compare scenarios from different events by comparing the similarities of abstraction levels of comparable instances. Occasionally, scenarios are used when someone is trying to persuade others to accept a future view, so the term is sometimes used to refer to stories that describe a future event (Gregory & Duran, 2001). Scenarios are important because they facilitate a holistic understanding of situations. Visser et al (2005:135) argue that `when important decisions have to be made, a clear and convincing argument can be made using a scenario of the interaction based on the design and the knowledge about its context`.

Scenarios often use time as a function. It enables seamless translations between users and systems through behaviours and actions. Elements such as context, objects, use and users are often combined when designers use scenarios. This creates problem spaces that allow the designer to question the factors that affect the design. This can even re-frame the core design problem leading the designer in a totally different direction in solving the initial problem or need. Bødker argued that:

> We have to work with scenarios as constructions meant to stage acting in the future, or to reflect on and illustrate problems with this action" and that "scenarios provide important means for making such a process possible because they offer specific settings and situations as a basis for communication between users, designers and usability people. (Bødker, 2000:73)

Scenarios can exist in several forms: story (narrative), situation, simulation, storyboard, sequence and structure (Alexander & Maiden, 2005:8-17). Examples of this are staged play sessions, storytelling (Lerdahl, 2001), exploratory design games (Brandt, 2006) and experience prototyping (Buchenau & Suri, 2000). Scenarios can be used to build relations between users, context and systems through actions and time. Such elements may be: 'what is done, where, by whom and when, by what means and in what way` (Bødker & Christiansen, 1994:9). Bødker and Christiansen (1994:9) also made a list of the qualities using scenarios in design:

- They support the build-up and use of a shared understanding among the design group.
- They exist in the borderland between experience and expectation.
- They are meant to provoke new ideas.
- They constitute a theoretical anchoring of an empirical "chaos".

Some of the main reasons for using scenarios in design are (Bødker, 2000:63):

- To present and situate solutions.
- To illustrate alternative solutions.
- To identify potential problems.

They further argued that scenarios are not physical entities themselves, but they need to be experienced and embodied through hands-on experience with the problems and situations. This can be done through workshops and games. The concept of how scenarios are materialised is important in relation to the scenario detailing. Bødker (2000) argued that a crude prototype or paper mock-up may have little value if the scenario is detailed and that this may lead the evaluation astray.

Scenarios have the ability to include various types of structures and data that represent a holistic perspective on connections between critical elements in design through actions. Designers use several types of scenarios during the design process. Some are continuous, such as concept videos, and some are discrete, such as visual storytelling (Buxton 2007) in which only a number of frames in continuous events are selected.

Connecting the UCD perspective to the conservative maritime design processes requires methods and tools that not only include the UCD perspective but also designs from other disciplines that are involved in the design processes. Scenarios can play a major role in maritime design processes that enhances the designers' ability to facilitate the design process in a strategic position in relation to other disciplines, such as in the helideck light design case study presented in publication 4. In this case study, the scenario played several leading roles during design, development, collaboration and marketing. Through the collaborative design session described involving several companies, disciplines and users, the scenarios communicated the engineering structure, manufacturing, assembly of product, contextual implications, functions, interaction solutions, landing procedures, environment implications, infrastructure (such as standards and verification) and user perspectives. Engineering and technical functions had the most focus, which is expected for this type of design process, but the scenario always kept the user perspectives in the design loop.

Being able to visualise scenarios based on reality and the future is critical for the scenario to work as a boundary object in interdisciplinary collaboration. The visualisation of scenarios must include several functions simultaneously for it to be efficient across disciplines and users. It does not only communicate the object being designed but also its use, actions, context, users and interaction. As described in publication 1, the actors and users also must be able to relate to this boundary object to recognise the situations and relate their expertise to it. If the material is too abstract, it may lead the actors astray as Bødker (2000) described, and the detailed boundary object may be considered as too rigid for conceptual design and direct the discussion toward insignificant details that are not important for conceptualisation.

Designers often present scenarios as steps in a sequence in which frames from main events or actions are drawn out, described and visualized. Questions that often come up are often related to what is happening in between the frames and how much time is used. Are there contextual relations that may be important in these in-between phases? If the boundary object is to include these in-between situations, it needs to have properties that make it change over time. Play and game theories are used in design processes and can be used to manage and facilitate scenario development to be used as boundary objects in design. Ehn (2008:158) referred to design projects as design games 'This design- game concept for exploring design processes is worked out on the basis of concepts of participation, communication, community, language and artifacts'. Brandt (2006) also discussed design games in which the game concept is based on a more structured framework and creates goals and meanings of play.

Exploratory play and construction play

Playing is an activity that all humans can relate to, and it is used to stimulate learning, creativity, skills and social communication (Garvey, 1990). Playing can be practiced unconsciously in design processes and can be seen as imaginative playing with possible future scenarios using several design techniques that involve elements of play. *Exploratory play* (Brown, 2013) is one such approach in which designers and actors use different types of artefacts to explore and reveal new aspects about objects, use situations and contexts. The difference between exploratory play and a traditional discussion is the ability to use the elements of play, such as bodily experience, being in a role, social interaction, object interaction, imagining and transformation. It is possible to pretend different aspects about the design, use and context to frame challenges or possibilities. These artefacts are often iterated during this process in what is referred to as *construction play*.

Construction play is not about engineering the actual object but about using different types of materials that are easy to transform into mock-up models that are then used in explorative play. I have used this approach in several case studies (Hjelseth, 2011; 2013; 2015) through collaborative design sessions in which we have collectively constructed future scenarios using game engines, such as in the Uddevalla harbour development case in which one of the actors shared his ideas of Uddevalla being a cruise ship destination. Based on this idea, we constructed a scenario in which a cruise ship sailed in the Uddevalla fjord. This scenario was then explored through positioning objects and examining different possibilities and issues that became obvious through the exploratory play.

It is often a challenge to persuade adults participate in playful design sessions. Pretending to be in a role or that an object has a different state may be embarrassing for adults, especially if they need to perform by making an object or drawing. In our design sessions during this research project, I have used collaborative drawing in many of the sessions. Some participants tried to hide their drawings, and some did not do any drawings, even if they had to make a drawing to present a new idea. Collaborative drawing solved some of these problems since the facilitator could draw someone's idea if they did not want to draw it.

Exploratory play and construction play often focus on single events in a short time span. When designing services or in situations in which several interactions and systems operate in a particular context over time, other methods, such as *storytelling* and *role play*, are needed.

Role play is also described as *role play simulation* (Paquette, 2012) in which new scenarios are created that can be used in several different ways. During role play, typically, a group pretends that individuals are in a character's role in a scene in which props can be physical or imagined. Role play creates an atmosphere of "being in the moment" that allows individuals and groups to explore situations and scenarios in detail by being projected into an experience (Simsarian, 2003). By being in the moment, it is possible to act on a present situation and change it to a preferred situation. Simsarian (2003) found the following benefits in the use of being in the moment and physicality using role play in design:

- Maintaining group focus on the activities at hand.
- Bringing teams onto the 'same page' through a shared vivid experience that involves participant's muscle memory.
- Deferring judgment while building on other's ideas.
- Building deeper understanding grounded in context.
- The ability to viscerally explore possibilities that may not be readily available in the world.

Improvisational theatre (Baumer & Magerko, 2009; Johnstone, 2012) has several similarities to role play when used in design; however, improvised theatre is aimed at entertainment with a humorous tone. The scene takes place in a type of black box in which context and situation are created in the moment by the actors' immediate response to input given by the audience or a director. The actors' talent in mimicking situations and turning a predictable situation into something unpredictable often creates an entertaining and humorous twist. In some types of improvisational theatre, the play is a type of game in which the audience votes for the best performance by individual actors or a group of actors. The play ends when an actor reaches twenty points and wins the game.

The game aspect can be used as a motivating factor for user engagement through competition; however, there are several issues and challenges related to this method. Artefacts of new designs do often need to be imagined or are often represented as abstract mock-ups. It can be a challenge to do the play in its intentioned real-world context, especially when the situations are related to safety or risk. Mimicking actions or behaviours of systems or objects can be a challenge if they do not exist. It can also be a challenge to identify the right perspective when observing an event and to find people to be part of the play. The play must be set up in a specific time and place to be facilitated. Playing the same scenario several times may not provide the same narrative because actors may behave a bit differently due to it being improvised. Using computers to play these scenarios in real-time have been shown to have several advantages in a design process because things can be fully visualised and behaviours can be programed.

Game design

To explore how scenarios could be developed through play and games, I have researched the field of game design, especially computer game design, to understand the frameworks used and the design process. This has also been important when creating my own concepts on how game engines can be used as tools for constructing and exploring scenarios for UCD design. It is the rules of play that set the theoretical framework for game design (Salen & Zimmerman, 2004). Game design is a discipline that focuses on the design of game play elements that structure the gaming experience. The game design discipline borrows knowledge from several other areas, such as mathematics, cognitive science, semiotics and cultural studies (Salen & Zimmerman, 2004:1). Jesse Schell (2008:10) argued 'The game is not the experience. The game enables the experience, but it is not the experience'. By this, he means that an experience only exists if someone is there to experience it through bodily senses and that the limitations are only set by its medium. The ultimate goal of a game is what Sheller (2008:11) defines as the artificial reality '…to be able to create experiences that are in no way limited by the constraints of the medium that delivers the experiences'.

Computer games

Games exist in several forms, such as card games, athletic games, board games, children's games and computer games. Computer games have several different features that make them very different from games such as card or board games. Chris Crawford (1984) has listed these features to describe the computer as a game medium:

1. Responsiveness to the *computer plasticity*. This principle is based on the computers and does not have the same boundary conditions as physical media games. Traditional board games are limited to the physical space of the board, while computer board games have no limits in levels.
2. The computer's ability to *motion as game referee*. The computer can work as an administrator of the game rules and logic. For example, when playing Monopoly on a physical board game, the players need to administrate the game rules (this also makes it possible to cheat). When playing Monopoly on a computer, the computer itself administrates the player's correct position after rolling the dices.
3. *Real-time play*. Traditional card or board games administrate evolution using turns. Computer games can use the gamers' interactions in a real-time response in which the interface input skills determine the game. This is typical in first person shooting games such as *Doom*.
4. *Intelligent opponents*. This is the computer's ability to play a part in the game. This is often referred to as *artificial intelligence* (AI), which makes the opponent unpredictable and mimics human intelligent logic.
5. *Limiting information*. By using a computer to limit the information given to solve a problem, it makes the player think and imagine the reality in new ways.
6. *Networking*. Computers are able to link players in different locations to play the same game. In the *World of Warcraft* action adventure game, ten million players can be playing simultaneously in the same virtual world.

The game design process

Because of the complexity of designing computer games, it often requires an interdisciplinary team of designers. These disciplines mainly consist of game designers, artists and programmers (Rouse, 2010). Figure 2 shows an example of the expertise areas typically used in computer game design and how they are linked.

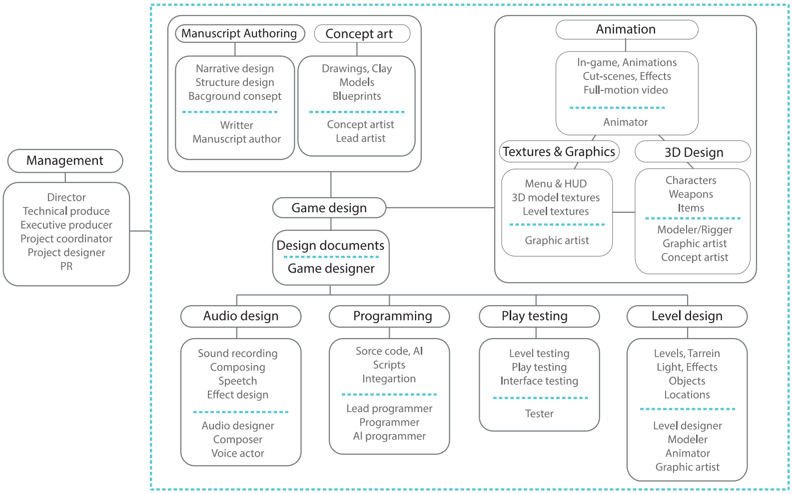

Figure 2. Example re-drawn based on expertise used in game design (Manninen et al., 2006:38. Redrawn). The structure of expertise used in designing computer games is complex because all the elements designed need to be placed in the same platform. This requires the game engine to incorporate all these roles and material on the same platform.

The game designers are in charge of the game experience and collaborate with the team of designers involved in the development process to achieve the goals. The game design process can be related to the game structure that creates the game experience and is involved in the beginning of the game concept development and throughout the game development process (Schell, 2008). Computer game design does not have step-by-step procedures; however, it often starts with a design concept similar to the product design processes. All roles used in in the game design process need cross-disciplinary relations to understand their impact on the game (Crawford, 1984).

Researching these structures of game design enabled me to better understand how the construction of scenarios can be developed using game technology, such as game engines. Through my case studies, I have found that I am using the same process structures and game features as are used in game design to create experiences through scenarios.

Summary

In this section, the theoretical foundation for the design in this thesis is described. To address the challenges of collaboration and complexity issues when designing for users in the maritime sector, a multidisciplinary approach to the design theory is needed. The manner in which designers manage wicked and ill-defined problems in relation to reflection in action and trial and error based approaches for solving problems has also been described. Design requires methods and tools in which knowledge and ideas can be materialised to reflect and explore problems to see new possibilities. This provides the opportunity to re-frame the initial problem and design situation, which creates new possibilities. UCD is the primary framework for the design discourse in this study, and it involves participatory design, the use of boundary objects and scenarios. Furthermore, I have described how play is central in scenario development and facilitates collaboration in design. Game design offers a potential structure and process to construct scenarios and play; however, the design research includes very little information regarding how scenarios should be constructed and facilitated during design sessions. There is also an issue regarding how to visualise and evolve scenarios over time. In the next section, simulation in UCD as a solution to these issues will be described.

SIMULATION FOR USER-CENTERED DESIGN

Computer games use several computational simulation techniques to visualise and facilitate game play. Some of the techniques used are based on mimicking real world conditions, such as physics, to create more life-like experiences with the objective of immersing the player into the game. In this thesis, I investigate how to model and simulate user scenarios and systems using a game engine as a design tool. I focus on the communicative and experiential aspects of simulation and examine how simulation as a part of scenarios can be used as critical artefacts and means to facilitate a design process to explore and reveal possible design solutions and problems in the maritime sector. This is a sector in which design and design research are beginning to make inroads where engineering perspectives and practices have previously been dominant. In this section, I will connect simulation to UCD practice by exploring how we can relate simulation as an established technique to a design practice that has had very little influence on its development in research and practice.

Through UCD, PD, scenarios and boundary objects as frameworks through play and game design, my approach is integrated into maritime design based on the challenges and opportunities found in its domain. Identifying the best way to involve industrial design in a conservative maritime innovation culture is a challenge because of the fundamental differences in approaching design problems. Solution-based methods through design thinking may be seen as more chaotic and incapable of handling the complexity of several types of systems interacting with users in a demanding operation at sea, and a more analytical approach is often believed to be necessary. Two major challenges are to translate knowledge between cultures and to design based on the knowledge about users across disciplines. To succeed in having several systems and operations that interact in a synchronised setting of high risk and high cost factors, new approaches in the design for users and contexts are required. I have found that simulation is an approach that is capable of including information and knowledge from several systems in the same evolving model from both engineering and user-centred perspectives as part of a holistic system, such as maritime operations.

Engineering has a long tradition of dealing with complex issues. By using computer simulations, engineers have been able to achieve the construction of structures that otherwise would have been impossible to achieve through other approaches. In general, simulation refers to the modelling of real world situations via representational, meditational and, increasingly, computational design techniques. Properties, behaviours and actors from these situations are mimicked and modelled to enable transformation via a system that allows them to be operationalized both contextually and temporally.

Computer simulations are often referred to as the use of computational functions to evolve a system over time. The simulation model is central to simulation design, and it defines how simulations are executed by a computer. It is based on mathematical equations, such as differential equations, that can run dynamic continuous simulations in which the simulation output creates a feedback loop phenomena (Zeigler et al., 2000). Simulation is used in several fields for several different purposes, such as physics, mechanical design, chemistry, simulators, entertainment and social science. It is also used in architecture in which it is used for environmental evolution simulations using visualisation tools represented through media, such as photographs, slides and films (Mahdjoubi & Wiltshire 2001).

It can be difficult to incorporate simulation into design because of its diversity in definitions, purposes and functions. Therefore, I needed to draw on other areas of science that have developed an understanding through the practice of simulation. Industrial designers have always adopted methods and tools from other industries and practice areas and applied them to the design process with the goal of creating better user experiences and designing for users' needs through products, systems and services; however, there have been limited applications of simulation theory, techniques and practice in design. It may be that the programming competence needed to understand and develop dynamic computer simulation techniques have been off limits to designers and that they have not determined how they should apply or use it in practice. To research the field of simulation, I have examined different definitions of simulation, its purpose of use and its relation to research. There are several definitions of simulation from different disciplinary perspectives:

- Engineering: ‘driving a model of a system with suitable inputs and observing the corresponding outputs’ (Bratley, Fox, & Schrage, 1987:11).
- Social and natural science: ‘a simulation imitates one process by another process’ (Hartmann, 2005:5).
- Multidisciplinary: ‘a simulation is an applied methodology that can describe the behaviour of that system using either a mathematical model or a symbolic model. Simply, simulation is the imitation of the operation of a real-world process or system over a period of time’ (Sokolowski & Banks, 2011:5).
- Art and science: ‘we have defined simulation as being experimentation via a model to gain information about a real world process or system’ (Shannon, 1998:10).

There are also several different purposes for application, such as entertainment, proof, discovery, education and training, engineering design, evaluation of direction or action alternatives, evaluation strategies for transformation and change, forecasting and prediction, performance evaluation, prototyping and concept evaluation, risk and safety assessment, sensitivity analysis and support for acquisition or procurement decisions (Axelrod, 1998; Birta & Arbez, 2007). Simulations also have various types of functions as research methods:

- Simulations as a technique: investigate the detailed dynamics of a system
- Simulations as a heuristic tool: develop hypotheses, models and theories
- Simulations as a substitute for an experiment: perform numerical experiments
- Simulations as a tool for experimentalists: support experiments
- Simulations as a pedagogical tool: gain understanding of a process (Hartmann, 2005:6)

In both natural and social sciences, simulations can be seen as a research method (Axelrod, 1998) for the creation and justification of new knowledge and theory development.

Simulation taxonomy

To base my research on simulator-supported UCD, it is important to inquire about different simulation models and what functions they offer. Shannon (1975:4) argued that: ‘a model is a representation of an object, system or idea in some form other than itself’. The time and evolution concept of simulation models can be both ‘static’ and ‘dynamic’ (Birta & Arbez, 2007:21). Visualisations of 3D models that are often presented and shaped in a design process can be described as a static simulation; however, if the model evolves over time, it can be described as dynamic. Winsberg describes a typical computer simulation technique concerning thermonuclear reactions in physical science:

> They began with a mathematical model depicting the time-evolution of the system being studied in terms of equations, or rules-of-evolution, for the variables of the model. The model was constructed (as is typical in the physical sciences) from a mixture of well-established theoretical principles, some physical insight, and some clever mathematical tricks. They then transformed the model into a computable algorithm, and the evolution of the computer was said to ‘simulate’ the evolution of the system in question. (Winsberg 2010:4)

Discrete, continuous, deterministic or stochastic simulation

Discrete and continuous simulations are based on dynamic systems in which the discrete approach only evolves in specific samples when the variables change in time steps. A continuous simulation is a simulation that continuously tracks the behaviour of the simulation model (Özgün & Barlas, 2009). Deterministic or stochastic are also terms used to describe a simulation model (Banks, Carson & Nelson, 1996). Deterministic models are based on known input data and identify which intervals of the data influence the system. If the entire simulation system is deterministic, the simulation will have the same output every time. Stochastic simulation models have variable input data or a random data input. These simulations will have different output data every time. Human-in-the-loop simulations (Narayanan & Kidambi, 2011) are an example of a stochastic model because including human behaviour as simulation input is unpredictable and different people may react in different ways. It is important to differentiate these simulation functions because it enables a specific discussion about simulation techniques and abstract simulation models. Because simulations are so widely used in design, it helps to apply these descriptions of simulation models to be aware of how the simulation is structured and functions. User-focused design disciplines have had little focus on simulation and therefore lack their own taxonomy when discussing simulations.

Simulation pitfalls

Winsberg (2010) used a model to describe the steps from theory to results through computer simulations. He described the challenges of validation and verification of the simulation and its result in relation to a real-world system. Because a simulation is a representation of a real-world system, it will never be accurate; however, more or less accurate simulations can be argued through benchmarking and analysis.

Another pitfall in simulation is that it can create a seductive experience through immersion. Turkle (2009) argued that this draws the attention away from the critical view on what the results are showing and how the simulation is modelled. Having control over the simulation tool is also described as one of the critical pitfalls in simulation. Turkle (2009) argued that designers should have the competence to know how the simulation tool shapes the simulation because it is critical for validation and verification.

In our approach to simulation using a game engine, the aim was not to create final results in the traditional sense of experimentation or testing. This means that the process of validation and verification was not that critical. Our aim was to use simulation to mimic the behaviour of objects using physics to create events that appear to be accurate according to existing and future scenarios related to the real world. In this sense, our aim was to create visual simulations of systems in action. In a sense, this is a risky path because how do we know if the behaviours simulated are more or less applicable in the real world?

The first real challenge regarding this question arose during the development of the helideck landing system with LysTech, as described in publications 4. The aim was to use simulations to create proof of the light system in use in different weather conditions at sea. Lystech had already done candela tests in light testing labs to prove that the system had the right values according to standards; however these testing laboratories are done in ideal conditions that do not exist in the real world, and they are not able to test the entire light system in one laboratory because of size limitations. I quickly realized that the only way to provide proof of its functions and usability was through real-world testing because there is no computational simulation tool that can provide accurate proof with the amount of factors involved.

I found that LysTech actually wanted the simulation as a means for marketing a product that did not yet exist in the real world. Initially, their view was that a simulation proof was needed to approach the users and possible costumers when they actually only needed these actors to believe in their product, their competence, and their ability to develop and produce the concept. When using our scenario simulation, it provided the means to discuss all of the challenges and to describe how they are solving them. The light visualization provided a means to show how the light should be experienced, rather than creating a discussion regarding whether or not the light simulation was reliable. I developed a technique using participatory users to model the simulation rather than trying to use real-world physical data based on 'how things ought to be' rather than 'what is…' (Cross, 1982).

Perspective on simulation for design

Transformation is central to the concept of simulation in which a system evolves and changes through simulation. This can be a self-sufficient loop in which the simulation of the system feeds new data into the system for further simulations. This approach to handling challenges is similar to the *Design Thinking* (Lawson and Dorst, 2009) approach in which models, artefacts and boundary objects can be used as discursive objects that provide new information that can be used for re-framing the problem or the creation of new models. These types of design processes enable learning about challenges to design new solutions.

Applying computer simulations to UCD is not straightforward. It is difficult to deftly model human behaviours for use in simulations; therefore, there is a need to develop comprehensive and pragmatic approaches for connecting human actions and technologically mediated renditions when using computer simulations in a user-centred design. In design research, there is little evidence of simulations that are applied for conceptualisation in UCD processes. If simulation is used in UCD, it focuses mainly on testing and evaluating users. There are also examples of physical-based simulation techniques in user-centred design, such as an 'age suit' that designers can wear to develop empathy when designing for the elderly (Hitchcock & Taylor, 2003). Also, several approaches of simulations are used for user tests and evaluations of products and prototypes as part of a design process (Aldoy & Evans, 2011; Kuutti et al., 2001; Mikchevitch et al., 2005; Manninen, 2000; Tideman et al., 2008; Gabbard et al., 1999; Zoltán et al., 2007). Simulators, game technology and scenarios are techniques used for human-in-the-loop integrations in a virtual environment.

The nearest related approach that uses simulations and game engines is the Experience-based Virtual Prototyping System (Kumar et al., 2010). The technique uses a game engine to develop the design review application to improve end-user review feedback. The application is used for late-stage prototype evaluations through the observation of end-users using the review application to simulate scenarios of pre-defined tasks. The main difference between this and my approach is the role of simulation. Through my research, I have found that creating virtual environments for testing human performance and behaviour requires very demanding simulations and interfaces. The process of testing also requires a process of verification and validation to create results that are reliable.

Areas such as task analysis, CSCW, VR, simulator research, e-learning, simulators and design for situation awareness are involved in using simulations in practice. All of these areas use simulation techniques that can relate to UCD in direct or indirect ways. Task analysis and situation awareness are areas that are directly applied in UCD when understanding users' situations and needs, while e-learning is more indirect because learning is an overall process when designing. Some of the simulation techniques and approaches used in some of these areas that are the most relevant to my research will be described in the following sections.

Simulation in task analysis

Task analysis is used in the process of observing and analysing human and system performance, errors and risk in terms of system goals. Simulations are then used as a method to study a system in advance before the real system is finished. It is used to study: 'appropriate working methods, ergonomics of control layout and design and identification sources of error, or to derive training recommendations' (Kirwan & Ainsworth, 1992:151). Kirwan and Ainsworth (1992) discuss the relevance of fidelity and the dynamics of simulation. If the dynamics of tasks are to be analysed, a dynamic simulation is needed. They argued that the fidelity in the level of detail and realism of a simulation is notoriously difficult to specify to yield the performance needed for analysis. Simulations of Human-Machine Interactions use techniques such as walk and talk troughs (Meister, 1986). Simulators have been used for the analysis of human errors in operation of nuclear control rooms (Beare & Dorris, 1983), helicopter task analysis (Hess et al., 2002) and simulations of driver performance (Cacciabue et al., 2007).

Simulation is not a task analysis technique itself, but it offers an environment in which tasks can be analysed. Several simulation techniques, such as walk through and talk through techniques, use physical mock-ups that represents the simulated space. These approaches to simulating user tasks are important in this research because they offer methods to apply user-centred methods in simulation that can be relevant for UCD.

Modelling and simulation in participatory design

In CSCW, computer research focuses on both the process of modelling and simulation as a means for collaboration and how to use simulation as part of the work design. Sierhuis and Selvin (1996:2) have created a framework on how to use the modelling part of simulation as an area for collaboration for analysis or design projects. They argued that: 'modeling reduces complexity by creating categorization and order through which people can create meaning, in order to get a shared understanding, which allows them to communicate'. Nine activities have been identified as part of the process of real world modelling. Modelling for collaboration using computers was also used in this study; however, Sierhuis and Selvin (1996) did not describe what role this collaboration has when simulating the co-created model. The game experience has also been used in CSCW to stimulate collaboration through play (Dietz, 2005).

Presently, new collaborative simulation workflows have been developed using modelling and simulation platforms on the internet with traditional system engineering simulation approaches (Wang et al., 2010). Agent-based simulations are also an example of how computer simulations are used in CSCW to coordinate development plans in a product development process (Zhang at el, 2008). The simulations are used to analyse, evaluate, predict and optimise different stages of product development based on human and organisation impact factors.

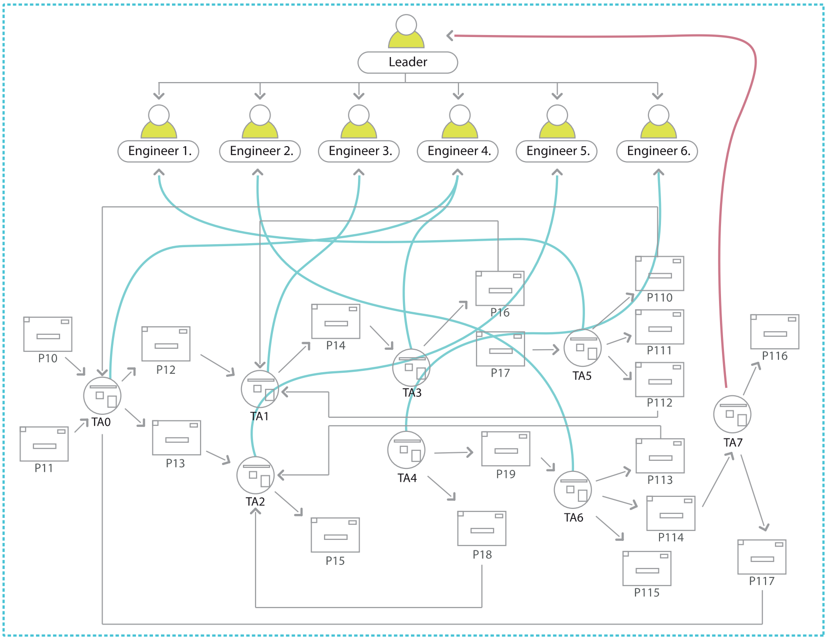

Figure 3. Integrated simulation model based on the team 7 experiment (Zhang at el, 2008:288. Redrawn). The flowchart shows how 6 engineers are performing tasks that are inter connected. By adding behaviours, trigger mechanism and time scale it is possible to simulate how the process might evolve, were management problems might arise and a time scale completing individual and complete operation.

Some of the key questions regarding these types of simulations involve the relation between modelling and the simulation of human factors and selecting simulation techniques. Humans are represented as mathematical equations rather than human-in-the-loop input (Figure 3), which shows the simulation model of human, task and product information. Task duration and work time is added to the model that is then simulated. The output can predict individual workloads through numerical output.

CSCW has also used game engines to visualise and interact with internet/LAN networks in a collaborative setting of multiple network administrators (Harrop & Armitage, 2006) Administration avatars are made visible, and their actions modifying the network are shown in real-time. The game engine itself becomes a product for network administration.

Virtual reality simulations in design

Virtual reality (VR) research has similar computational approaches to natural and social sciences in applying simulations in virtual environments. For the past 20 years, VR has been viewed as having potential for applications in design; however, it has not been adopted by design education or in practice as an efficient way of approaching problems and challenges. In the VR research related to UCD by Thalen and Voort (2012), the main focus was to use VR to create a realistic user experience in a virtual environment interacting through computer user interfaces with the goal of providing user feedback from a design concept through user testing.

Talen and Voort (2012) has conducted a series of in-depth interviews with over 40 designers, engineers and managers about their use of VR in product development processes. Talen found that their use of VR was limited to the use of CAD and 3D displays for engineering reviews. It was also difficult for the actors to relate new VR applications to their own practice; VR applications also had no fast-end or easy-to-use interfaces for designers, leading to the need for an external company to facilitate the process. It is important to note that VR applications are developed for computer engineers and typically not for designers with less knowledge about programming. In some cases, the use of VR techniques is referred to as virtual prototyping regarding product development (Schaaf & Thompson, 1997). It involves the use of simulation when testing aspects of the prototype. Recently, VR technology has become available for a mass market of developers though products such as the Oculus Rift SDK. The technology is reliable and inexpensive. Many of the problems regarding the latency of tracking sensors resulting in people becoming ill have been alleviated by the new technology. Leading technology and social media companies, such as Facebook and Samsung, are investing heavily in VR technologies. Game engines that can create content for VR have also become accessible and much easier to use without expert knowledge in programming.

Simulators combine the use of computer simulations of user scenarios with human input through realistic interfaces for evaluation or training employees. Simulators provide several of the functions and techniques used in this study for simulated scenarios in UCD; however, the simulation tools used to create simulators are mainly designed to be used by expert programmers rather than industrial designers. Still, there are several interesting aspects in simulators and simulator design processes that are relevant for UCD processes because they include human factors as part of the simulation loop.

A simulator, such as a flight training simulator, uses a combination of computer simulations and human-in-the-loop integration. The user becomes part of the dynamic continuous simulation that is also the simulation tool. In simulators, real-time graphics are needed to mimic real-world conditions based on human input. This creates a continuous loop in which the simulation output is observed by the users that react to the situation using input devices that affect the simulation. A game is a simulation tool to model and simulate game experiences with graphical and audio output for entertainment. The equation used to mimic real-world conditions is often based on natural scientific research, such as in physics, to create model life-like behaviours to be experienced.

Human-in-the-loop

Human-in-the-loop refers to the human input of a system loop (Narayanan & Kidambi, 2011). Procedural simulation using simulators are often used as examples of human-in-the-loop simulations in which the goal is to use the simulator for education and training (Dawson, 2006) or as usability tests in which human-factors and performance are tested. It may be easy to draw the conclusion that the software for creating such simulators should be preferred in a conceptual UCD process; however, it was difficult to move forward in the research when trying to apply simulation software from the simulator field because of the knowledge barrier in computer coding and software accessibility.

E-learning is a research field that uses simulations for teaching and learning processes (Aldrich, 2003). Serious gaming, a subdomain in e-learning, uses game logic and technology to engage users and to develop knowledge and skills (Susi et al., 2007). Teachers often write their own books that are used in teaching; however, designing computer simulations requires a different type of skills and knowledge that most teachers do not possess. This is why a close relationship between the pedagogic developers and the game designers (Figure 4) is needed when developing *serious games*

(Liu & Ding, 2009). Industrial designers have basic knowledge about 3D software that is very easily transferable to game engine editors. Also, some designers have limited knowledge in scripting.

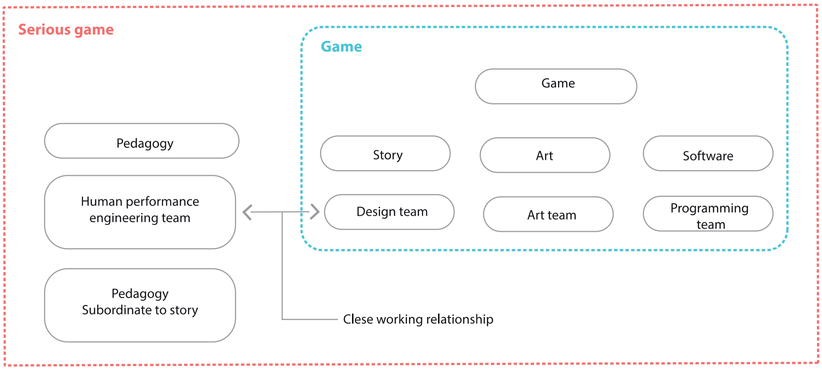

Figure 4. Model based on the relationship between serious games and game design (Liu & Ding, 2009. Redrawn). The game design process (Figure 2) is brought in as a component in the designing of design material for learning and education. The pedagogy expertise is working closely with the game designer to structure and design the learning experience.

Serious gaming is a research field that is closely related to my view of design simulation because it focuses on the process of learning through the actions of interacting with computer simulations; however, its evolution is often pre-defined based on actions to fit a pedagogical model rather than designing. In the maritime sector, simulators are used for training and product development when testing prototypes. One example is the installation of new lifeboat facilities on the *Statoil Visund* platform in which the operation was optimized using simulated physics and training staff in the procedures (Maslin, 2013).

Designers also lack the skills of using computer codes, but new interface technology has made coding much easier. In my research, I have also experimented on using game engines as a teaching device in physics. In a test case, I used a supply vessel to create a scenario in which weight could be added as ship cargo. If higher waves were added, the cargo would slide to one side of the ship, making the ship heel (Figure 5). Because the simulation was done in real-time, it was possible to interact with the scenario to change the factors, and the effects were instant. This was used to train naval students in how cargo may behave at sea. In my research, I have used game technology model simulations and facilitated human-in the-loop integration in the conceptual stages of design.

Figure 5. Screen capture of a physics simulation of cargo handling on a platform supply vessel. The barrels on deck represents heavy steal cylinders. While the simulation is running, it is possible to move them around on deck to change the load condition. This will affect the ship stability.

Simulators for future scenarios

Like the maritime context at sea, the domain of outer space is a place in which it is difficult, costly and dangerous to test design concepts. NASA has tried to use different aspects of computer simulations to create future scenarios to predict, explore and reveal implications of future space missions on planet explorations using astronauts and remotely operated rovers (Figure 6). By creating virtual environments that simulate several systems at the same time and in which the simulation outputs interact, it becomes a situation in which situations are simulated in a simulation. Through this approach, NASA has been able to simplify the means of devising complex products and projects based on better interactions between an interdisciplinary team of experts (Piovano et al., 2012). Thus, it was not only the rover drivers that were part of the human-in-the-loop but also engineers investigating and exploring possible challenges and problems related to the overall design.

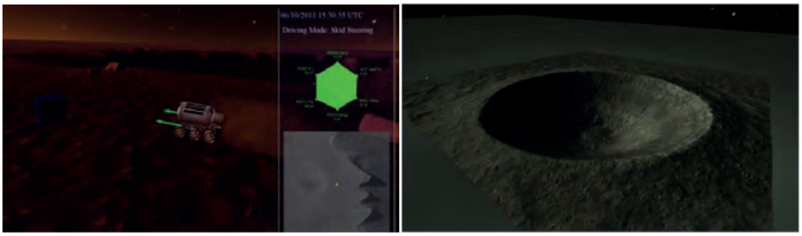

Figure 6. Frame taken from Rover Simulator (RoSi) software based on VERITAS framework (Thales Alenia Space Italia, COSE Centre). In the Collaborative System Engineering Centre (COSE Centre), the Virtual Simulation & Design Support Tools have been developed in the frame of the STEPS Project (2009-2012), a project co-founded by EU on the 'Misura Piattaforme Innovative' - POR FESR 2007/2013. The rover behaviour is modelled based on it physical properties (left picture) and then tested in landscape structure on Mars (right picture).

Summary

In this section, I have described the concept of simulation and its relation to UCD. I argue that UCD lacks a tradition of taxonomy when referring to simulation as part of design and that this is important when classifying methods and tools for simulation. Natural and social sciences have a framework of taxonomy that is used to describe simulation models. The same taxonomy can be applied to simulations in UCD.

I have described some pitfalls in simulations. In a UCD approach to simulation, it is important to be aware of these pitfalls, such as validation and verification, which are often a topic of discussion in natural and social science simulations. Using simulations to test products will require validation and verification of the simulation model. This may be a complex matter in UCD because a simulation is only a representation of the real world, and important hidden structures and factors may be left out. Immersion is also a pitfall in simulation; however, UCD manages these same issues in creating prototypes and models in design processes by keeping abstraction on a level that is relevant for the design problem.

Furthermore, I have described several approaches to simulation in design disciplines that are user and human-related, such as task analysis in human factors, work load simulation in CSCW, simulation in VR, human-in-the-loop and simulators. Finally, I described how NASA has used simulations in creating realistic scenarios to explore Mars. Several of these techniques can be applied to simulation in UCD to support collaboration and user involvement for conceptual design. In the next section, I will describe how game engines can work as design tools for simulations and the construction of scenarios in UCD.

GAME ENGINES AS TOOLS FOR DESIGN

Simulation tools are computer software that allow simulations to be modelled and run using computer hardware. The computer hardware is able to calculate several billions of processes per second, often using several central processing units (CPU) simultaneously. This means that a large amount of data can be used to shape the simulation model and system that would be impossible with other physical techniques. The simulation tools can also be used to visualise the simulation process and simulation outputs.

Some simulation tools are third party software that is connected to a design software. This means that modelling the content is easier when applying them to the simulation tools. An example of this is *Solidworks*, which is mainly 3D construction software that also has *Solidworks Simulation* software as an extension, allowing the simulation to be applied in the same virtual environment.

The mediation of the simulation modelling process and simulation output results is often part of the simulation tool. An electro circuit engineering simulation model is often visualised in a schematic view, and the simulation process is visualised through a graph displaying output results (Mengué & Vignat, 2001). Some simulations, such as a fifth element (FEM) analysis, can be used in a 3D virtual environment in which the simulation model is based on boundary conditions, such as forces and 3D geometry, that are affected based on the design. The simulation process is not visualised, but the results are visualised depending on static or dynamic functions.

My approach has been to use the simulation functions in game engines and apply them to a design perspective to mimic existing and future user scenarios. I have tested several different simulation tools and techniques to mimic real-world behaviours to facilitate collaboration and a user-centred design. Some such as Catia and Solidworks, are based on mechanical engineering design, and some like Maxwell Render and RealFlow, emerge from the animation and game industry. Game engines are interesting to apply in UCD because they offer software frameworks that allow several simulation techniques on the same platform and virtual environment. This allows for the modelling and simulation of a content-rich environment with several systems and behaviours to be simulated and interact simultaneously. This also creates the possibility to approach issues of complexity when designing for users in the maritime sector.

Game engines

Recent trends in interaction design and other industry contexts show that designers are adopting game engines and coding to design interactive games, interfaces and systems. Examples of this can be found in the research by Thalen and Van der Voort (2011; 2012) regarding how designing screen interface experiences using Unity. Unity has become part of the interaction design courses at the Oslo school of Architecture and Design.

Design practice has always been influenced by technology trends, both in design outcomes and parts of the design process. These trends often try to change how we think about and practice design and are therefore an important part of evolving design methods and tools.

A game engine is a framework used in the process of creating and running computer games. It is software that provides a technical infrastructure for games and renders everything seen and interacted with in the game world (Nideffer, 2003). Game engines are also used to create games for platforms, such as mobile phones, Xbox, PlayStation or personal computers. Game engines use functions such as 2D or 3D graphics-rendering engine, object collision detection, physics engine, animation integration, artificial intelligence, sound integration, scripting and network extensions.

When these game elements are used in a non-gaming field to improve or design user experiences, it is referred to as *gamification* (Deterding et al., 2011).

Game engines have traditionally been developed for computer engineers who are experts in computer coding; however, because of an increased demand for more games to be developed and competition between game engine developers, software technology and computer hardware (Nvidia, ATI), the push for the game engines to be distributed to more users has increased. This has resulted in better usability of game engine editor workflows and interfaces in which people with skills other than computer science can apply it in their work. My research has focused on what the implementation of game engines means for design practice and the design outcomes of different levels.

The engine of game engines

Today, middleware software, such as *CryEngine*, *Unity* and *Unreal Engine*, are among the most popular game engines. This competitive race has given developers the ability to design for several platforms, such as iOS, Android, Xbox and PlayStation, at the same time and provided license agreements of use that are affordable for smaller developers and hobby users.

As a designer and researcher, the game engine is a type of black box experience in which data and information can be compiled into a system that translates it into the dynamic experience on the screen. This black box 'exists to abstract the (sometime platform-dependent) details of doing common game-related tasks, like rendering, physics, and input, so that developers (artists, designers, scripters and, yes, even other programmers) can focus on the details that make their games unique' (Ward, 2008:1). Research conducted on game engines is often related to highly technical computer engineering and is often presented in conferences such as SIGGRAPH. In the 1980s, game engines such as SCUMM from LucasArts and SCI from Sierra provided middleware game engines that were used in almost every adventure game published (Ward, 2008). When the first person shooter game *Doom* was introduced in 1993, it introduced a new type of game engine using 3D models and modular software extensions that had a huge impact on the way games are designed now by enabling programmers to hack the existing game and reuse its functions in creating totally new games (Simpson, 2002). Currently, game engine developers are using these communities to finance their game engine development through licensing the engine of a commercial service to anyone who would like to use it. Robert Nedeffer argued:

> We must expand the notion of what constitutes the networked game 'engine' to include not only hardware and software infrastructure, but also the interpersonal and culturally driven social networks that emerge in relation to the applications written for that infrastructure. (Nedeffer, 2004:9)

When I used CryEngine in my research, the CryTek game engine company developers' forum played an important role in learning and exploring the game engine. The software is highly complex, and several functions and bugs need to be explained and discussed. It is important to be creative when searching for solutions because it may be necessary to combine existing solutions into new ones. The forum offers an opportunity to be part of a global community in which the focus is to utilize the game technology in the best possible way; however, all members of this community are dependent on CryTek as the engine distributer. The community has no control over the software, and this can be an issue when the software is not evolving in the direction needed for game design.

Telling stories through games

The main function of game engines is to provide a software framework for computer game developers so new games can be designed and developed. Computer games today have developed into sophisticated systems in which the "game story" is developing during its play based on user input. These systems are simulated based on a number of input factors that can be changed during real-time interaction.

Storytelling mediated through computers may not have been used much in user-centred designs, but they are widely developed in the narrative game industry. Early adventure computer games from the 1990s such as *The Secret of Monkey Island* enabled gamers to explore adventure worlds and interact with them to reveal a ready-made story. Gamers did not create the story they were in, but they needed to combine the systems of different relations for the story to continue. Storytelling in design is also about combining and relating systems but with an open ending. Newer adventure games have become more cinematic with sophisticated animation using motion-tracing and hi-fidelity graphics.

Game design has developed functions using simulation for on-the-fly creation of embedded and emergent narratives (Wei, 2010). It is a combination of what narrative the designer has pre-made and how the player can act on this to create his or her own narrative. The sum of this adds up to the total game play experience. The main reason for this combination is to provide a story that the player can act on and at the same time give the game player the experience of controlling how the story evolves. In my research, I have used the same principles to trigger discussions on specific areas of interests. The virtual scenarios can have a high level of detail, and the focus can be changed in real-time. This creates a feeling that every possible situation can be facilitated on-the-fly, enabling the user or actor to take control of the telling of the story.

Other applications using game engines

Because game engines have the ability to combine different types of media, technical functions and interactions, they have been adopted in other scientific fields for science experiments (Lewis & Jacobson, 2002), serious games for educational purposes (Johnson et al., 2005) and for simulators (Craighead et al., 2007) instead of for entertainment. Game engines have also been used in user-centred design directions, such as an Experience-based Virtual Prototyping System (Kumar et al., 2011) and VR applications (Thalen & Voort, 2012). Both of these research projects are closely related to this research but with different approaches and focuses.

Simulation in game engines

The entertainment industry has long used different types of simulations to mimic the real world and to create interactive computer game experiences. The interesting thing about game engines is the ability to hold several different types of simulations in the same virtual world and visualise them at the same time, including both static and dynamic simulations with discrete and continuous model systems. Individual simulation systems can provide inputs for other systems to shape multi-modular simulations. Gravity and sea waves are examples of dynamic continuous simulations that will affect an object of mass continuously in the virtual world. Behaviours such as AI interaction and event triggers can be regarded as discrete simulations because they are triggered by sequential or random inputs.

It is important to remember that not everything that looks like dynamic simulations in the game engine are dynamic simulations. To create less complex simulation systems, it is possible to have a layered structured simulation in which the physics collision detections of an AI are not connected to its navigation controller. This means that if the AI human is walking, it is not the physical legs or the interaction between foot and ground that makes him go forward. A linear animation that mimics walking is triggered by the move control of going forward. Game engines such as the CryEngine also have character editors in which interactive animations can be made when the editor simulates morphs between movements.

The main difference between how simulation is used in entertainment in contrast to science is that in entertainment, a simulation is not meant to be used as a research method for conducting experiments to produce new knowledge. Its main focus is about creating user experiences; however, tools such as game engines use natural and social science research to mimic the real world as accurately as possible. This also means that tools such as game engines are not designed to create simulation results such as physics stress because its main function is about mimicking and not testing. Thus, UCD practice can be seen as a process of designing user needs and experiences. Applying stress test simulations to products that are designed based on user experience is also important, but it is usually not applied in the conceptual process of designing.

Real time

As described in the section about play and game design, both *being in the moment* and *real-time* provide several benefits in games and play. The two differences are the human experience and the system experience of real-time in the moment (Crawford, 1984).

Simulation is a process in which evolution is part of time and space. Because time is a boundary condition in simulations, it can be modified. Simulations of star galaxies' evolution (Kippenhahn, Weigert, & Weiss, 2012) with a time period of over hundreds of thousands of years or nuclear reactions (Blattel et al., 1993) in fractions of a second are examples of how time can be modified.

Continuous simulations move from real-time to run-time and output time which the result can be analysed (Cellier & Kofman, 2006). When dealing with real-time, continuous or discrete event simulations such as in game engines, these time faces run in actual clock time, and the sequential phases are not experienced in the workflow. In our research, this type of real-time simulation has been very important for the workflow because when iterations of the simulated scenarios are done in collaborative design sessions, its effects are immediate without any delay of post processing. Moreover, by using the game engine editor, it is also possible to edit parts of the simulation in real-time, including free camera movement and contextual boundary conditions, such as light, ocean wave height and wind as well as AI and object properties, such as moving objects, changing physical states and behaviour actions. The result of this creates a feeling of the simulation being tangible (interactive) in which moving an object in the virtual environment using the computer mouse is an experience of extension to the virtual world.

Real-world and live real-time data

An interesting concept about real-time scenarios is the possibility of implementing real-world data into the system. Because the simulated world and the real-world use the same clock time, this becomes a possibility. In the Oslo fjord crisis case described in publication 3 and 4, we considered extending its function toward using real-world inputs. One suggestion was using AIS signals or GPS trackers in large scale exercises at sea, such as a crisis exercise. It could be possible to implement this data in a debriefing session or as live input in a computer simulation when the exercise is being performed.

Real-time rendering involves making images rapidly on the computer. It is the most highly interactive area of computer graphics. An image appears on the screen, the viewer acts or reacts, and this feedback affects what is generated next. 'This cycle of reaction and rendering happens at a rapid enough rate that the viewer does not see individual images, but rather becomes immersed in a dynamic process' (Möller at al., 2008:18). The drawback of using real-time simulation is that if you have a scenario that takes 12 hours to evolve, you must wait the entire time. When I have used the behaviour triggering logic, I have focused on smaller events in a sequence that is critical. The real-time functions and the use of real-world and live data extends the immersion in the relation between the real and the virtual not only for visualisation but also for the underlying mathematical model shaping behaviours and actions through time.

Immersion and mediating simulation

The use of realistic concept visualisations and models has been seen as having a negative effect on creating further creative solutions (Parsons, 2009). When game engines as used for simulation, the goal is to create entertaining experiences often mimicking real-world conditions as realistically as possible. Being able to simulate systems does not mean that the data outputs are possible to understand. The mathematical models actually only provide numerical outputs that are then translated into models that allow that data to be understood and analysed. Scientific visualisation and information visualisation are important research subjects and have provided insight into a new understanding of systems and nature (Tory & Moller, 2004). The visual output is also dependent on simulation time. If the calculation can run faster than actual clock time, a simulation dependent on time can take a shorter time to produce. If the simulation runs at the same time as clock time, it is called a real-time simulation.

Virtual reality experience

Virtual reality research is a field that often uses game engines for simulation in which the main focus is to simulate user experiences through computer interfaces and the ultimate goal is to make it impossible for humans to distinguish between reality and virtual reality (Saggio & Ferrari, 2012) VR research has similar computational approaches to natural and social sciences in applying simulations in virtual environments. For the past twenty years, VR has been viewed as having potential for applications in design; however, it has not been adopted by design education or in practice as an efficient way to approach problems and challenges.

A combination of VR and the current perception of reality is referred to as *Augmented Reality* (AR) (Azuma, 1997). The use of simulation techniques, such as situated simulations (Liestøl & Morrison, 2014), is used to combine virtual environments and visualization simulation in a real world setting through mobile devices, such as mobile phones and tablets. This creates a connection between two dimensions co-existing in the same experience space creating an immersed link between the existing and the future possibilities.

Summary

In this section, I have described game engines that are used to create computer games. Through combining different media and simulation techniques on the same software platform, game developers are able to develop embedded and emergent narratives in computer games. These narratives change according to user behaviour and act as simulation input changing the game story. Game engines have also been used in UCD, such as in Experience-based virtual prototyping and VR applications. I also discussed the time element of simulations and scenarios and how real-world data and live real-time data can be used to model simulations. Time is seen in the perspective of how simulation and time affect immersion. Game engines offer a very powerful platform to combine different types of media that can be used in combination with several simulation techniques to evolve and mimic real-world behaviours; however, its potential in design has not been fully identified and needs further research.

Summary

In this chapter, I have presented perspectives on design, simulations for user-centred design and game engines as design tools. This created the theoretical foundation to answer the main research question: How can new approaches through simulation be developed to answer the challenges of UCD in the front end of maritime innovation? Maritime design involves multidisciplinary designs of products and systems of risk and critical safety operations. Human failure is also recognised as the major contributor of maritime accidents; however, UCD is used at a very limited degree in the design of maritime applications. My approach has been to investigate how UCD processes can address such challenges and complexity. A good foundation for collaboration between actors and users is one of the key elements when dealing with these complex matters. Participatory design and co-design have long been used in developing methods and tools to facilitate collaboration and user involvement in the UCD domain. Boundary objects are often used in collaborative design sessions to facilitate the discursive process of learning, exploring and designing; however, these boundary objects do not necessary need to be the design objects itself but should work as a critical artefacts by framing problems and solutions. Scenarios are boundary objects that can include context, users, systems and time in the same object. This makes scenarios efficient tools for understanding complex operations and combining several elements into the same object for inquiry.

The challenge related to scenarios involves how they are to become boundary objects that are materialised. It is a challenge to find a medium that can facilitate all of the events and details that are required when creating scenarios of maritime operations. When the context is also unavailable for the team of designers, it can be very difficult to imagine how a designed situation may appear. Designers are experts in making visualisations of future situations; however, there are few tools that deal with evolution and time factors. It can also be difficult to understand the connections between systems, users and context without observing their relations in action. Simulation is a method that has been used in several other disciplines to mimic the real world and how it evolves over time in both existing and future situations; however, user-focused design disciplines computational simulation techniques have been used to a very limited degree. Game engines are tools that are designed to create game experiences that also use several simulation techniques to mimic the real world. Game engines can also be used to visualise and simulate scenarios for UCD. In the next chapter, several case studies will be described in which game engines have been used to construct, simulate, explore and iterate scenarios as a means for collaboration in UCD.

Chapter 3: Research Methods and Design Techniques

In this chapter, I will explain the research methods used to explore the use of visualisation and simulation tools and techniques in maritime collaborative design sessions. My research has been an explorative process to understand the design and innovation culture in the maritime sector and to create design processes and tools that support the UCD approach. The chapter has two main sections: Research Methods and Design Techniques and Practice.

RESEARCH METHODS

To research the relations between design, process, collaboration, innovation and visualisation, an explorative approach has been used. The exploratory research approach allows for a diverse focus when creating the research design, and it is often used as a method when there is little research or information about a subject to sort or identifying a subject (Shields & Rangarajan, 2013). Using this exploratory approach, I have focused on using two qualitative methodical directions: *action research* (Avison, 1997; Hollingsworth, 1997; Miller, 1994) and *research by design* (Morrison and Sevaldson, 2010). To understand how I reached the conclusion of this thesis in which I created a framework for a contextual simulation process, the beginning of the research scope that triggered the events, research and process shaping the concepts will be described. The starting point and the PhD project description was to examine the relations between maritime innovation design, collaboration processes, scenarios, visualisation and simulation techniques.

An action through practice-based inquiry

I have used action research as a research framework in which the practice activity itself is research. Archer (1995:11) argued that 'there are circumstances where the best or only way to shed light on a proposition, a principle, a material, a process or a function is to attempt to construct something, or to enact something, calculated to explore, embody or test it'; however, to generalise from such research can often be a challenge because it is dependent on factors such as time, people and circumstances from the real world in which the researcher has little control over actions that take place. Action research can be described as a practice-based activity conducted by practitioners that is almost always situation specific. In comparison with other scientific research traditions, such as fundamental research and applied research, action research is usually non-objective, and the results and findings are generalizable to a limited degree; however, the limitations of the research method allow insight into findings that is not possible to research using other methods, and it often provides hypotheses that are relevant for more fundamental research (Archer, 1995).

Design itself is a process of creation. Therefore, it is important to use research action methods that allow for studying phenomena through real-life design practice. In this research, I refer to the use of cases (Yin, 2009) in which real-world innovation is a focus directly connected to new product development, stakeholders, companies and business strategies. To really understand all relations in these cases, I have used participatory action research (Cahill, 2007; Miller, 1994). Participatory action research allows the researcher to directly take part and engage in the research subject. Design knowledge is largely based on a tacit competence in which 'we know more than we can tell` (Polanyi, 2009:4) and also on what is possible to be objectively observed. Therefore, the best way to do design research is to embody and practice it. Research by design is based on a practice-based inquiry that involves the relation between practice and theory. The design techniques are part of the research methods for knowledge production (Morrison, 2010). Through research by design, I have explored several aspects of simulation tools and techniques and its relations in design practice in partnership and through consultation with industry players, stakeholders and users. I developed a design laboratory and a set of mediated representations from sketches and videos from field studies to full-scale scenario simulations in game engines that have been central in understanding design in the maritime sector and the use of visualisation and simulation in creating a user-centred design.

Nine designers and actors involved in the cases have been interviewed using qualitative interview techniques (Kvale & Rygge, 2009). Each interview lasted approximately 30 minutes using video and audio recordings. I chose to use video when recording the interviews because visualisations and videos from the design projects were used as a reference in the interview it self.

An interview guide was created for the interviews that focused on collaborative and communicative aspects during the design sessions. The interview data was interoperated based on how the actors and designers were able explore the concepts and relate their own experience and ideas to the group. All of the interviews were transcribed and analysed through comparison with the practice-based experience from the design processes. Because these were qualitative interviews, they were used as indicators for how the boundary object and collaborations were experienced in the design process rather than final research results. Some of the transcriptions are presented on page 78 and 89 as part of the case studies.

Three collaborative design sessions used as case studies were documented using video recordings (Iversen & Buur, 2003). These recordings were used as a reference when analysing the process of collaboration and the use of tools. Video and audio recordings were used in some cases to obtain a more in-depth understanding of how the actors and users perceived the collaborative design session process. For some of the videos, a continuous stream of video data was used, and some consisted of several video clips.

This is a video that was recorded during the collaborative design sessions:

PGS simulator design: 86 minutes.
Uddevalla harbour design: 42 minutes.
Oslo fjord crisis handling: Fist session 35 minutes.
Oslofjord crisis handling: Session 80 minutes.
PSV scenario development: 104 minutes.
Helideck light session: 34 minutes.

The interviews and video recordings offered different approaches in researching collaborative design sessions. The interviews focused on capturing the users and actors experiences from the design session after the design process, and the design session videos captured the actual design process. It can be difficult for a user or actor to evaluate a design process through an interview because their experience does not necessarily determine whether or not the session was efficient as a process in that design stage. It can also be difficult to describe the design session setting and events in the sessions based on interviews done after the sessions because the actors and researchers do not necessarily see important elements when they are present in the collaborative design session. When video recording the collaborative design sessions, it is easier to analyse how the visualisation and simulation acted as part of facilitating the process and the role of the researcher and designer through participatory action research on a more objective level.

Ethical considerations

All of the interviews were done with similar processes in which the persons that was interviewed was informed about what the interview was about and how the data was to be used in research. Through an information sheet, they were also informed about their rights, such as stopping the interview at any moment without reason, and that the recordings and data were to be stored according to the Norwegian Data Protection Authority and research ethical requirements. The persons interviewed and the researcher signed a declaration of consent in two copies based on the interview terms.

Having the role of both designer and researcher creates interest conflicts. It is important to value the commercial interest a design project may have and apply the right design strategic approaches in the projects' best interests; however, this may not be the same direction as the research focus.

DESIGN TECHNIQUES AND PRACTICE

In this section, I will describe the empirical research process used to investigate the main research question: How can new approaches through simulation be developed to answer the challenges of UCD in the front end of maritime innovation?

Through research by design, I have participated in several design projects represented as cases in which several design techniques and technology have been applied. Through practice-based research, I have been able to study and analyse the complexity and challenges of UCD in the maritime sector and use this information to shape new techniques and processes to address these issues.

I now describe and discus three areas that shape the argumentation on the three concepts presented in the next chapter on a design-oriented view on simulation, gamification and real-time. The first section describes how I have investigated different simulation techniques mainly for visualisation purposes. The second section discusses how I studied the maritime industry design processes through a simulator design project in which the main focus was field studies. The third section describes the design of a design laboratory environment to explore and design new techniques and technology for collaboration and participatory design. At the end of each section, I will present a summary and findings.

Simulation research in practice

In the beginning of my PhD research, I explored several visualisation and simulation techniques in design projects when exploring new tools and processes for the SimSam-lab. These visualisation simulation cases created the background that led to the use of real-time simulations and game engines. I will present some of these cases in which several visualisation and simulation techniques were tested to describe the research background. Several of the simulation techniques tested did not directly focus on UCD or collaboration but were used to explore the possibilities of simulation and visualisation techniques in describing processes, experiences and materiality.

Mechanical simulation

One of the first design projects I completed was to visualise a large-scale rapid manufacturing process based on a new manufacturing technique using a large crane and injection concrete on an inflatable mould. The technique was patented by Prof. Jan Capjon, my former supervisor. The idea was to use *Solidworks* and its mechanic simulation tool to mimic the concept of the manufacturing process. Solidworks is a CAD tool used for construction tasks, such as in mechanical engineering. The manufacturing process is based on using inflatable moulds. I will describe the visualisation and simulation process by discussing the research situation.

I had just reinstalled a new version of Windows Vista 64bit and installed more RAM on my PC after several crashes using Vista 32bit. Using the 32bit Solidworks version, I imported and textured the 3D models of a crane system from Autodesk Inventor (3D CAD construction tool) made by mechanical engineering students. The simulation was modelled using geometrical constraints, and a helix motion pattern was made in which the concrete was to be added to the inflatable mould; however, when running the simulation, the computer stalled and was not able to simulate or produce the visual output.

After several trials and searches on the internet, I discovered that it was a hardware problem, and I changed to the 64 bit version, which was able to handle bigger assemblies of 3D objects in mechanical simulations. Based on the motion pattern, the crane moved accordingly based on the movement parameters and constraints triggered by an engine movement parameter. When simulating the process, it was calculated in a pre-view mode that was slower than real-time.

After finishing the calculations of the simulation, a series of frames was made, and they could be played as an animation. If a change was made to the simulation, it had to be re-calculated. This job was time-consuming, and several trials and errors were made before the end result could be traced using the built in Solidworks renderer. The animation of the simulation produced an impression of what the manufacturing process may look like (Figure 7).

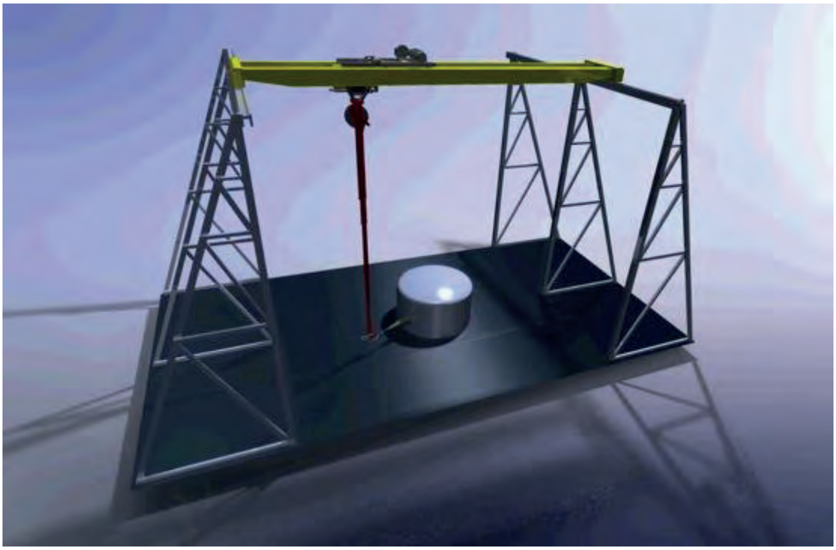

Figure 7. Frame from the animation of the simulated manufacturing process. A specially designed software automation system is controlling the care movements based on pathways created from a 3D model. The lightweight cornet is injected on the inflatable mould. The mould is deflated after the concrete hardens and then used again for the next injection process. This makes a rapid and economic way of making large structures in concrete.

The animation showed how the crane moved according to the mould, but it did not actually show the layers of concrete being built. Doing this required a different type of simulation that could mimic liquids. To do this, I started to investigate and learn RealFlow, a fluid dynamic simulation software for the animation industry designed by NextLimit Technologies.

Through this study of mechanical simulation, I found that systems with physical constraints can be simulated to visualise how components behave individually in the system. The objects are part of a physical space and will act on collisions with other objects. This means that new scenarios could be detected based on physical limitations and the constraints of the physical objects. For design, this means that form and function on a mechanical level can be explored through simulations in a design project.

Fluid dynamic simulation

The RealFlow simulation tool uses particles and physics to mimic fluids to behave realistically. RealFlow has been used in movies such as the *Lord of the Rings*, which caught the attention of NASA in acquiring similar solutions for engineering. XFlow is a fluid dynamic simulation software for engineering that produces numerical outputs for analyses based on particles. This technology, which moved from the animation industry to engineering, shows that it is not only natural science that influences the entertainment industry but also the other way around.

Using different tutorials, I learned the basic functions of RealFlow, enabling me to test my own ideas. Most of the trials were just for fun to try to mimic the real world. When using particle simulations, the end results can be unexpected and produce interesting shapes. It is also important to be able to master visualisation of liquids when working with maritime innovation projects.

One of the ideas for using the large scale rapid manufacturing technology was to produce floating islands that could be used for different applications, such as movable water filtering units or fish farms.

The aim was to create a visualisation of how the island would look at sea. First, I constructed the 3D object in Catia (3D CAD construction tool) and exported it as a STEP file to be imported in Autodeks Maya (animation software). Then, I used RealFlow to simulate ocean waves in a geometric mesh that I assembled with the floating island in Maya by texturing and rendering the scene (Figure 8).

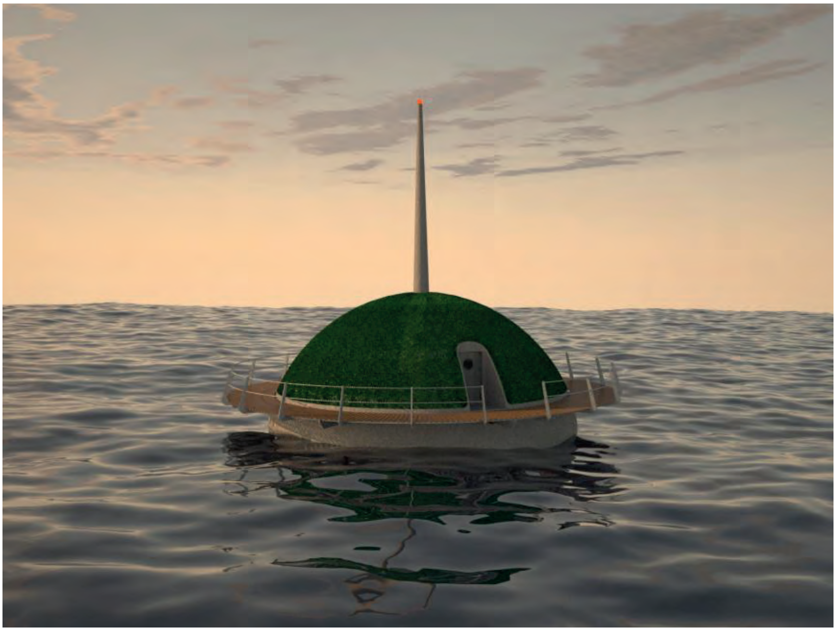

Figure 8. Rendering of floating island and waves simulated in RealFlow. The island was to house water cleaning technology and anchored to the sea floor. The waves were simulated to mimic the ocean and how the floating island might float on its surface.

The next test I did in RealFlow was to make designed objects interact with the particle simulation by using the ship hull from an offshore supply vessel from the *Ulstein Bridge Concept* research project at the Oslo School of Architecture and design (Figure 9). The aim was to simulate the ship design in a rogue wave. There was no actual need for this in the design project, but I did it as a test regarding how to simulate buoyancy in waves as a visual effect in conceptual design.

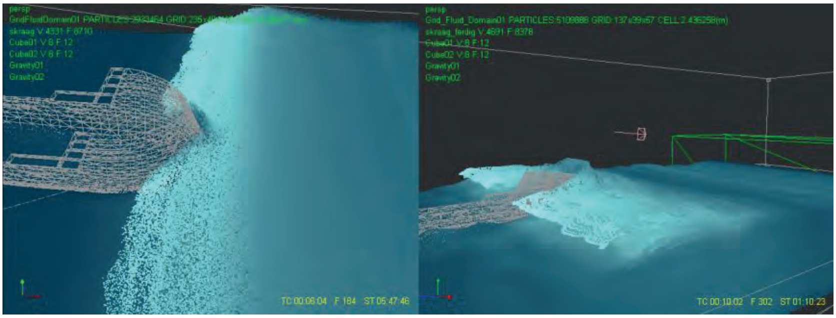

Figure 9. Screen captures from the RealFlow software. Ship hull and 5 million particles simulated to mimic the behaviour of the ship hull in a rough wave. A wave hitting the ship might give ideas e.g. how to place equipment on deck to minimize large spaces of water flow that can become a risk for the ship crew.

The simulation technology used is called Hybrido and is designed for large scale particle simulations. The process of modelling the simulation is based on setting up boundary conditions, such as gravity, particle demos and a simulation boundary box. 3D objects, such as the hull, need to be simplified, or the simulation would take too long time to run. The hull mass and gravity point had to be correct in order for the hull to have the right buoyancy. For design, this means that it is possible to use virtual fluids as a design material during conceptualisation. It can be used to describe a behaviour of an object or the behaviour of fluids on a design level that is aimed for exploration and play rather than testing for engineering purposes.

Soft body physics simulation

I did a test trying to model behaviour based on the experience of something other than technical data. The aim was to simulate bouncy balls based on the Sony Bravia commercial made by Fallon London (Figure 10). Getting the balls to have the right bouncy behaviour was the most challenging because there are several physical parameters that make up the material behaviours. In soft body physics, the forces interacting with the object actually make the object deform. For a bouncy ball, this reaction happens very fast, making the object bounce.

Figure 10. Frame from the animation of the bouncy ball soft body physics simulation experiment. The balls starts bouncing from a sett height and bounces down a small slope towards the camera. This makes some of the balls come out of focus, but at the same time gives a sense of space.

When physical properties are given to an object and its behaviour can be observed through action, it can give information about its materiality that can only be explored through time. Soft body physics simulations allow not only the material behaviours and its properties to be perceptual explored, but it can be used to shape the properties and behaviours of a material. This means that designers can not only experience the material behaviour of concepts but also design the material properties as well.

Light simulation

Simulating light is what I have done in previous tests and experiments when rendering 3D objects. Maxwell Render is a fascinating 3D model-rendering tool. It uses light physics to calculate how light hits materials and bounces further in space. It is therefore also called a light simulator. The light settings in these renderings are based on finding the best way to represent the 3D objects. It is a different matter when trying to mimic light from a real word setting and will require a different approach. When designing the SimSam-lab, I reached a stage during development in which I had to make a decision on what type of light system to use. Because the lab room was not built yet, it was difficult to know how the light would affect the room. A solution to this was to try simulating the lamps from the supplier using the IES (Illuminating Engineering Society of North America) format. The IES format is specified to describe photometric data, such as intensity distribution, and has been approved through standard ANSI/IESNA LM-63-2002. The Maxwell light simulation software is able to import these IES files and use them in virtual environments to simulate light.

I first conducted tests using spheres and fluid to test the effects using light translations in a Maxwell Render called Multilight. The Multilight technology allows the light sources to be changed and updated after simulations without recalculating the entire picture. Using this method, it is possible to create an animation of the light in a post-rendering process (Figure 11).

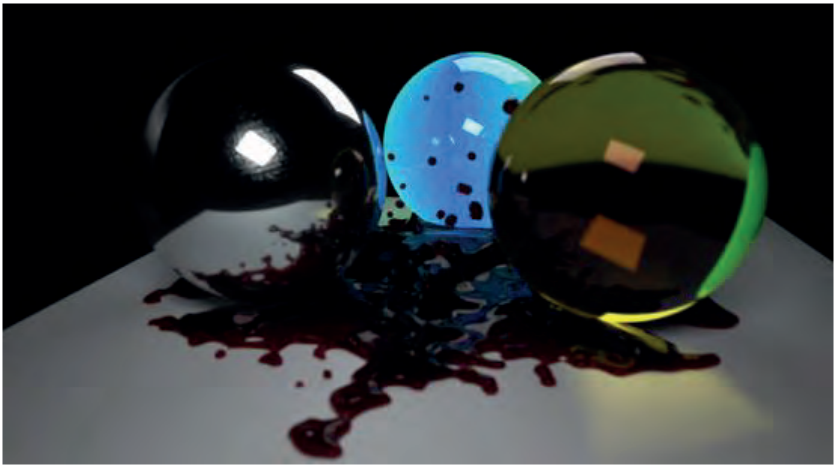

Figure 11. Screen capture of the animation of a Multilight test. The light sources in the scene of three spheres and a fluid dynamic simulation was animated in a post-rendering process. The light sources in the scene are first simulated in a rendering process and then they save the simulation model so it can be updated after rendering.

After testing, I created 3D models of the lamps I was considering using and added the light sources that I had downloaded from the manufacturer's website. I also added the touch table screen and the projector areas to create an impression of how it may look (Figure 12).

Figure 12. Screen capture from the SimSam-lab light simulation mixing multiple light sources. The room was modelled based on the architect drawings of the room. The light coerce in the sealing was based on the IES light diagram from the manufacturer.

Most of these initial simulations were simply tests to describe and visualise some elements about a design and not about constructing the design itself. Some simulations involved creating static visual representations, and some involved simulating or mimicking the real world or a future process. My aim was to explore the possibility of using different computational simulation techniques in a design practice and to determine what effects they may have on the design and collaborative design processes. Using these different simulation techniques presented it communicated behaviour and functions of matters that are often abstract or can only be experienced visually through action. Behaviours through mechanical properties and physics are elements that become available as a design material through these simulations. Designed experiences with the factor of time-defining behaviours on a conceptual level can only be experienced through motion and time. Sometimes, it can be difficult to say what the simulation is communicating and what it means for design, but at the same time, it adds new dimensions in understanding hidden structures and elements to the virtual world as material for conceptualising scenarios and experiences.

However, rendering these dynamic translations of systems, behaviours, objects and contexts requires the understanding of other types of knowledge than what the typical industrial designer acquires. To explore the field of simulation in a UCD, I have had to learn new things about computer programing, 3D modelling and physics. I also had to learn about the process of using game engines.

A design material requires not only the ability to be used and shaped for designing, but it also needs to be accessible in the process of reflection-in-action on an individual and collective level. Using the simulation techniques tested discussed above requires a lot of computing time and sometimes several processes to produce the results. Using these techniques in a collaborative design session is therefore a challenge because of the overall workflow. These physical simulation technique tests are mainly object-oriented and show very little about the contextual implications of the design. In the next section, I describe the impotence and complexity of contextual relations when designing for the maritime sector.

Understanding maritime complexity through field studies

For designing a simulator with Kongsberg Simulation and Petroleum Geo Services (PGS), I did field studies on the seismic vessel *Ramform Vanguard* in the North Sea (Figure 13). Through the use of field studies, it was possible to study several elements of the operation to be used when designing a seismic simulator for streamer recovery operations. Through this case, I also obtained an understanding of the maritime culture on board the ship and the issues and challenges of conducting observations of complex critical safety maritime operations.

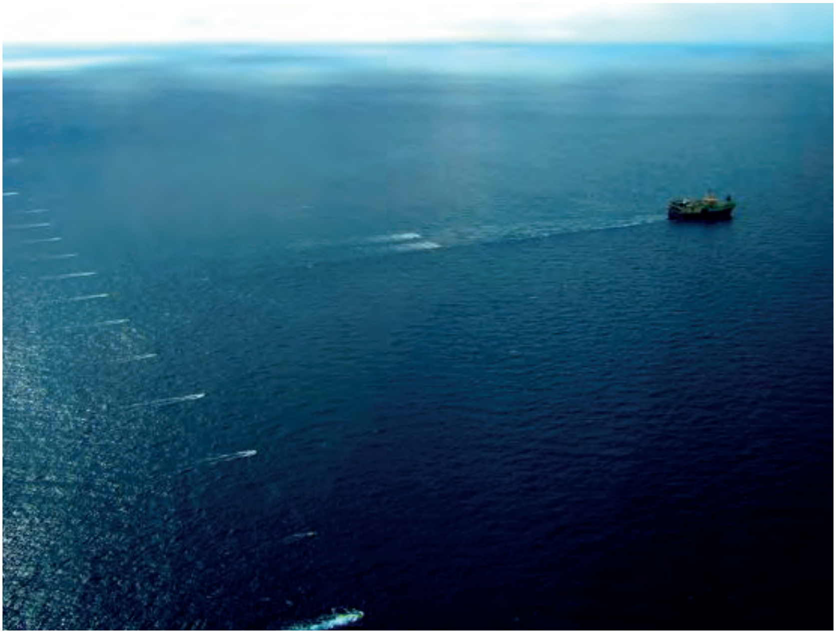

Figure 13. Picture from the *Ramform Vanguard* seismic ship with all 16 streamers deployed. The seismic screamers are stretched out 1.5km using hydrodynamic doors on each side of the streamer configuration. When all are deployed the length can be up to 8km. This makes the streamer operation cover an area of 12km^2 with a speed of 5knot making it the largest moving object in the world. (Photo: PGS)

The complexity of maritime simulators

Keeping people present and active in the design loop is central when it comes to user scenarios. The Kongsberg Offshore Simulator (Figure 14) shows the complexity of a drilling rig anchor operation and the high-end technology needed to simulate and visualize the scenario. In this simulation, detailed 3D models were used with real-time visualisation and real-time precise physics and hydrodynamic models to create an encompassing experience of being at sea. Dynamic positioning operators performed the operation using real interface console devices. All of the ship navigation systems and interfaces were integrated into the simulator and communicated with the virtual ship. Communication with the drill rig and the surrounding ships was carried out through a simulated VHF interface to a control room connected to the simulator. The simulation room had special ventilation and noise reduction because of the heat noise created by the computer servers and screens.

Figure 14. An anchor handling vessel simulator shows how complex scenarios can be simulated and used as a training facility and for the assessment of dynamic positioning operators. This is an anchor handling operation that requires very precise manoeuvring keeping attention to engine load, anchor angle to the rig, deck and ring communication. (Photo: Kongsberg Simulation)

All of these matters are part of creating a realistic simulation of offshore operations for training purposes. When designing for maritime operations, such technologies and methods have largely been limited because of issues of complexity in use. While simulations have been used in this sector, rarely are they applied to UCD processes in which an interdisciplinary team of designers needs to understand systems, users and tasks in relation to the holistic operation scenario; however, it can be seen in a recent example of a concept ship bridge that combines the co-design of complex systems, interactions and daily work operations through the use of simulators (Kristiansen & Nordby, 2013).

Design experience from maritime simulator innovation project

When designing a simulator, it is important to understand the technology and functions when people are interacting with machines. It is also important to understand the human behaviour in these situations and how each task is performed. There is no prior simulator designed for training on seismic streamer recovery operations, and the recovery procedures are based on individual crew and winch operator experience. It is important to create a model that can create a shared understanding of the operation for designers and developers that is used for design and as a guide when creating the final product. To do this, we applied several different approaches, such as mock-ups, models, user-probes, storytelling and videotaping by users (Figure 15).

Figure 15. Frame capture from observation video. Example of wood model used in the design process when trying to understand the seismic technology and functions.

Through several meetings, a group of simulator engineers and actors from the seismic company discussed and tried to understand the operation scenarios; however, it was very challenging to discuss details even if we had several descriptions, photos and videos of the situations. The challenge was to understand what was being done by the crew and how the equipment was functioning because several tasks were performed simultaneously on several areas on the ship.

I suggested that alternate methods may be considered to address the gaps in converged action and interpretation (Hjelseth 2012). By using the new technology of action cameras, it is possible to synchronize video observations from multiple cameras in high resolution and in low light sensitivity. The light weight of the cameras allows workers to wear the cameras when performing the operations. This technique allows designers to investigate real situations on a micro and macro view level in high-risk contexts at sea.

Offshore field studies

When investigating the existing situations of maritime operations, it has been critical to observe the situation and have the ability to communicate with the people involved before and after the operation. I have used field studies as design and research methods to study demanding critical operations in the offshore industry. Field studies are also described as field research and ethnography (Arnold, 2005). Field studies are activities performed during the design process in which the designer gathers information about the situation that is to be designed. This is done to understand the existing situation to design preferred ones. Lurås and Nordby (2014) described an approach for design-driven field research that also uses design reflection as part of the field research process. A reflective process on the design is done through experiencing life at sea and design mapping that involves collecting specific data, such as tasks, equipment and mapping the work environment.

Conducting field studies of offshore operations is a challenge because the context of the operation is limited, and the tasks involve critical safety and risk elements. Even performing observations can be a challenge in high seas.

To fly a helicopter to the offshore installation and ships, a four-day safety course is needed. In the safety course, the student is strapped in a helicopter model using a four-point seatbelt and then is pulled under water in a pool and turned 180 degrees to mimic the helicopter capsizing (Figure 16). Then, the student needs to get out using the escape routes through the helicopter windows wearing a full survival suit. Basic fire fighting and cardiopulmonary resuscitation (CPR) is also part of the safety course.

Figure 16. Picture from the safety course with the helicopter capsizing exercise. The helicopter body will turn 180 degrees hitting the water. This makes orientating escape routes difficult. Divers are used in case of emergency situations. (Photo: Falck Nutec)

When I was on the *Ramform Vanguard* seismic ship, I first went through the observation procedures with the winch operator to discuss the operation and where and when it was useful to record the situation using action cameras. By using the new technology of action cameras, it is possible to synchronize video observations from multiple cameras in high resolution and in low light sensitivity. The lightweight of the cameras allows workers to wear the cameras when performing the operations (Figure 17).

Figure 17. Video capture of the seismic recovery operation with multiple view angles showing the overall operation view and tasks performed by crew and winch operators this method gives a micro and macro perspective of the operation. Five camera angels are used and synchronised simultaneously.

The concept of micro and macro views draws on levels of mediated activity. Through the micro (small) view, I was able to see hand movements, the buttons that were pushed and how tools were used. The macro (large) view showed the four kilometre streamers and the crew possessions. It was the combination of the synchronisation of these views that enabled us to understand the seismic streamer recovery operation from the user's point of view to an operational and contextual level. One interviewee, for example, mentioned that the video material was very important to help everyone understand what was happening and that having good video material is not to be underestimated when trying to understand these types of operations (Hjelseth, 2013). The multiple camera method only allowed for observing situations of a past operation in a limited time span; however, it did not provide the possibilities to create situations based on accidents or possible future challenges and scenarios, which is relevant to a design process.

The video was used to create a detailed picture of the seismic recovery operation when designing the simulator (Figure 18), and it is also used when training new seismic personnel.

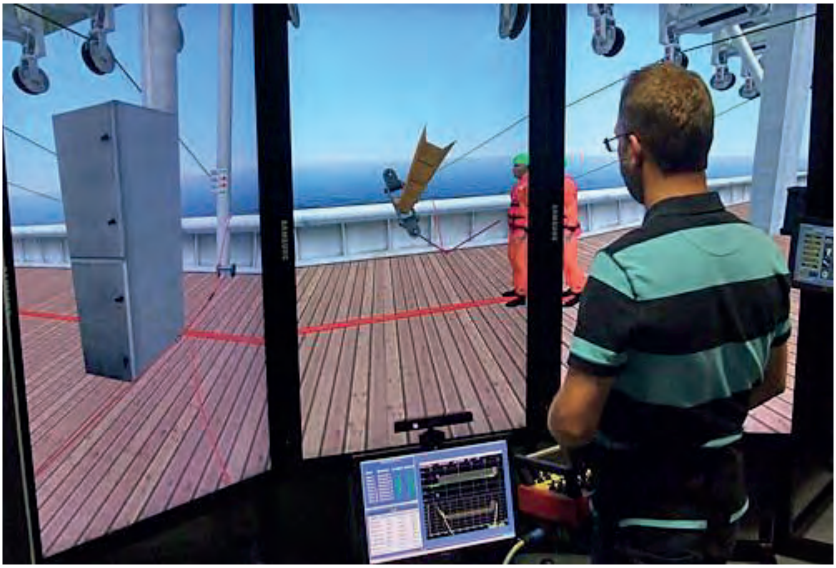

Figure 18. Picture from the finished seismic simulator. The student using the simulator uses a motion sensor to move an avatar around on deck. The winch control used is the same as they are using offshore. The instrument panel shows seismic streamer depth and position in the water. (Photo: Kongsberg)

Designing simulator concepts

When working with simulator concepts, computer renderings of 3D models presenting possible concepts were created (Figure 19). The problem with using this technique was that it did not present the design concept scenarios as continuous actions, and it was not known if the simulator software could produce the same graphic quality. The aim was to test the Kongsberg simulator software as a design tool in the conceptualisation phase to attempt to understand the multiple user tasks and to explore new concepts on how the interaction between the virtual environment and the interface devices could be presented.

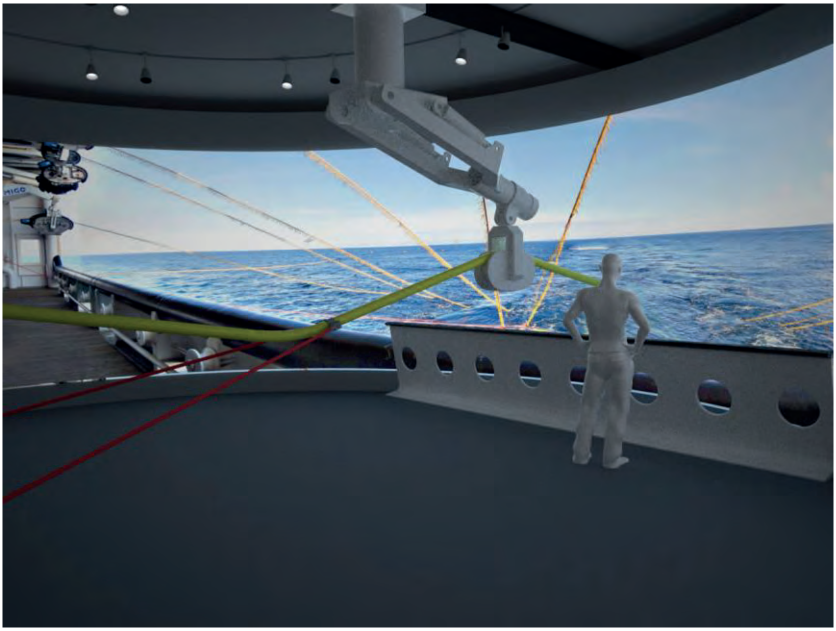

Figure 19. Computer rendering of a seismic simulator design concept. The simulator uses a 360-degree projection screen with physical installation of winches. The simulator is then used by multiple users when winching in the streamers and detaching streamer equipment in the same process.

I spoke with several simulationists at Kongsberg Simulation; however, I quickly found that the simulator software did not have an editor user interface where the simulators are designed. All 3D objects needed to be written in to the simulation using code for the 3D file and placing it in the virtual environment. After writing the code, it would be possible to test it in the simulator, which would visualise our code to see if the desired result was obtained. This makes it very difficult to use it as a conceptual tool in design because of the designers lack of programing competence and the modelling is not possible using real-time interactions. Because of the complexity of the simulator, I began a search for alternative software technologies both for simulation and visualisation in real-time and to be used on multiple screens in an immersive system.

Through the seismic streamer recovery simulator design project and field studies, I gained an impression on the types of complexities related to interdisciplinary design teams working with demanding maritime operations. Through the field studies, I discovered how difficult and complex the task can be to observe demanding maritime operations. Observations are needed in several operation levels, such as first person cameras and macro cameras capturing the overall operation so tasks and operations can be connected. I also found that existing simulator design tools are difficult to use in the conceptualisation of simulators; however, it is important to have design tools that allow behaviours, time and system actions to be simulated to explore events that cannot be captured through observations.

Design-lab

The maritime sector is often regarded as very conservative in terms of radical design concepts. 'Why change something when it is already working' is often the attitude representing the industries view on innovation. Our goal was to see if design competence could trigger more radical concepts. Our focus was to use new visualization technology and techniques as a means to support collaboration between interdisciplinary users and actors in collaborative design sessions. One of the maritime innovation complexities is the diversity of knowledge in systems, operations, tasks and technology that are often difficult to communicate between different disciplines.

To facilitate this process of knowledge transfer and collective creativity for conceptualisation, Professor Jan Capjon (co-supervisor) and I designed a laboratory to house a simulator and design collaboration facility (Figure 20). Referring to the domain of simulation and collaboration, we called our design laboratory (Koskinen et al., 2012; Dell'Era & Verganti 2009) *SimSam*. Laboratories are often explained as controlled environments in which scientific experiments are performed.

A design-lab is an environment designed to test new approaches for designing methods, processes, settings and tools. The difference between a regular meeting room and a design-lab is that all of the elements of the environment are designed for the purpose of design and collaboration with the possibility of documenting the activity. The lab had to facilitate interactive communication in small group design meetings (Olson et al., 1992) described as collaborative design sessions (Gül & Maher, 2009; Kim & Maher, 2008).

The SimSam-lab has 15 spotlights in the ceiling that can be adjusted individually, sound absorbing materials in the ceiling and 360 degree walls that work as continuous projection areas using 7 projectors with a total resolution of 14440x1200 pixels. This wall is made of a perforated textile for sound absorption and ventilation. There are five power and network outlets in the floor. There are different types of furniture used for different types of design settings, such as presentation mode and work mode. A 42inch touch screen is used for multiple user interactions and information underlay for boundary objects, such as maps. There are three cameras for recording and one portable microphone. There is one 360 degree camera for external connections. There are different types of drawing tools and a fast scanner for scanning multiple drawings at once. There are also Whiteboards, a 7.2 sound system and several types of design and visualisation software tools.

Figure 20. Frame from a video in a collaborative design session with Kongsberg Maritime in the SimSam-lab in which several design techniques and technology have been explored. The tool Cooliris was used on a 360-degree projection wall to view several images of operation simultaneously. (Left) A ship simulator was also used during the workshops as a reference to the ship systems.

Collaborative design sessions

Using the design-lab, I carried out trials on 9 collaborative design sessions that have been documented using photo, audio and video. Different types of visualization and technology were to be used as boundary objects (Star, 2010; Star, 1989; Star & Griesemer, 1989) for co-design and co-creation (Sanders & Stappers, 2008) when digital media was developed and communicated (Capjon and Hjelseth, 2012). Several co-design and participatory design methods and tools have been developed to support such collaboration, such as computer systems (Büscher, Eriksen, Kristensen, &

Mogensen, 2004), embedding expert users (Humphreys, Leung, & Weakley, 2008), collaborative sketching (Johansson, 2006), materiality (Jacucci & Wagner, 2007) and tangible user interfaces (Kim & Maher, 2008), all of which were situated in a frame of participatory design and innovation (Dalsgaard & Halskov, 2010).

Through the collaborative design sessions in a lab setting, I discovered that the dynamical capabilities of the use of 3D real-time visualizations and simulations were not only able to facilitate and visualize the design concept but could also be used as a design conversation method (Glock, 2009) using real-time manipulation in a workshop setting. I was able to create more immersed experiences in user scenarios by employing game engines and subsequently applied this to finding new methods of working with complex maritime user scenarios at sea (Hjelseth, 2013).

Scenarios in collaborative design sessions

In collaborative design sessions, I have explored ways of using narratives to trigger and shape discussions on identified needs (Boje, 2001). Through the use of previous accident reports (Norway, 2010), I reconstructed the wider scenarios of an accident in collaborative design sessions and the design-lab setting.

By using scenarios, I have been able to connect the design practice to user and actor participation in collaborative design sessions that drive UCD through the means of tools facilitated by a designer. I also combined digital live Automatic Identification System (AIS) from ships using Google Earth on a touch screen with physical models to implement live data into the discussion (Figure 21).

In the process of shaping the different scenarios, I used several different mediation techniques (Rosson & Carroll, 2003), such as scale maps and models (Bratteteig & Wagner, 2010), drawings, videos, storytelling (Beckman & Barry, 2009) and personas (Miaskiewicz & Kozar, 2011) These methods were efficient in creating a platform for discussion and for problem re-framing techniques to track changes (Kruger & Cross, 2006; Lawson & Dorst, 2009; Poulsen & Thøgersen, 2011; Schön, 1983).

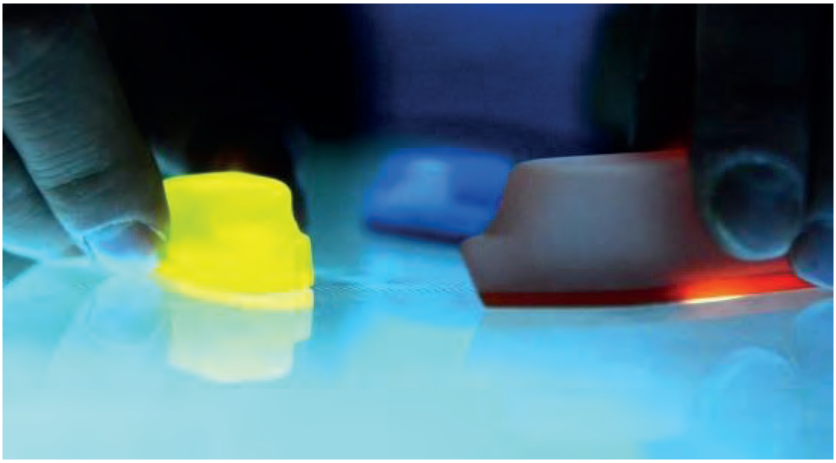

Figure 21. Picture of acrylic sandblasted ship models on a SUR40 touch screen. The ship models had a transparent surface that was sand blasted to give it a glow effect on top of the screen. The idea of this was to make the touch table interact with the models using id-tags.

Designing the SimSam-lab

The process of designing the SimSam-lab was in itself a research process on collaboration and participation, as described in publication 1. Through a series of meeting and collaborative design sessions, pictures of hi-fidelity visualisations of 3D models were used as boundary objects to facilitate the co-design process of designing the SimSam-lab. In these collaborative design sessions, I involved users and actors representing different areas of the maritime industry.

When constructing the visualisations that were to be used in the design sessions, I found it necessary to use several types of 3D software to create all elements needed. The lab was to be created and built in a new research building at the Vestfold University College Campus, so I only had technical drawings available as a starting point. Catia was used to draw in all objects in the right size so that I could produce drawings that the architects could use as a reference, which is shown in Figure 22.

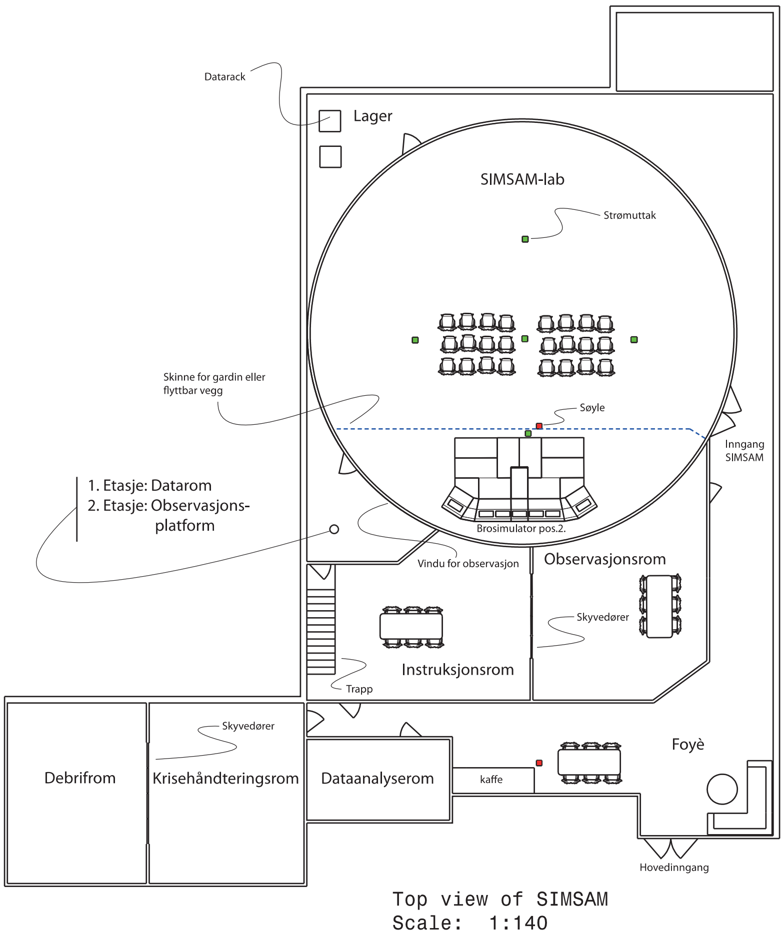

Figure 22. Technical drawing based on plan drawings from the architect, which was used in organising the different lab functionalities.

However, the 3D technical CAD drawings did not indicate how I was going to use the facilities. Catia did not give me the right level of realism that I wanted for our collaborative sessions with user involvement, so I used the animation software Maya to create renderings with lighting textures and 3D humans created in Poser using the facility (Figure 23). Part of this research aim was to find possible and good workflows for transferring the 3D objects between the different platforms. Through a series of trials using different formats and plugins, I found a suitable pipeline between the technical construction software and the animation software.

Figure 23. Rendering from Maya with light, textures and personas. We placed the large projection screen in the room with other objects that are often used in design sessions.

The 3D model and 2D drawings were created through a series of collaborative design sessions in which maritime design applications for the lab were co-created with users and actors based on the representations. My main focus in this research was to identify which of the 3D visualisations had more realism that affected the collaboration setting. One of the participating designers argued in the interview:

> External partners and users were not able to understand the 2D sketches, but this changed when we started using the 3D visualizations. (Hjelseth, 2011:7)

One of the users also argued:

> They were open to the concept, but their enthusiasm was limited because they did not see the possibilities in the maritime sector, but when we started to discuss the simulator using the 3D visualizations, their understanding of the concept started to grow. They started then to see new possibilities using the concept within their maritime field. (Hjelseth, 2011:7)

Focusing on using 3D visualisations resulted in a process in which new ideas had to be incorporated in between the design sessions because of the time consuming rendering process of new visualisations. This meant that changes to the boundary objects could not be done in action during the collaborative sessions; however, I was able to use the same 3D models throughout the entire front end design process from the first ideas to financing the concept by the EU MarKIS network and the decision to implement the concept by the Vestfold University College Board. Because the 3D software is based on layers, I found that data could be added or removed and represented in a way that targets the goal for the individual innovation faces. Using 3D visualisations in this way proved to be efficient and precise.

These 3D visualisations were just static simulations representing systems in relation to users. It does not give the notion of actually simulating the behaviours and actions that take place in relation to time. Based on these tests in the collaborative design sessions, I shifted the focus to the use of 3D software that was able to visualise a high level of detailed 3D objects and textures in real time with the possibility of being changed during collaborative design sessions.

Revealing real-time functions for collaboration using game engines

In the next phase of my research, I explored the use of computational simulation tools for design in collaborative design processes. My first idea was to use simulation techniques to simulate future user experiences, as in VR, but for collaborative settings; however, after testing and practicing different approaches, I found that my focus was not actually on simulating an experience through a computer interface but to model the contextual relations and use simulation to describe actions, behaviours, events and scenarios through time. Thus, the process that I used involves tools and media as speculative boundary objects rather than representing the boundary objects as part of the final design experience.

At that time, Crytek had published their first free software development kit (SDK) version of their game engine CryEngine that had been used for games such as Crysis and Far Cry, which are known for the high-level of advanced computer 3D graphics. My first experience opening the SDK editor with the Forest example level was enthusiasm. I was amazed by the smooth moment and graphics that seemed to have no limits in detail. The test level invited me to experiment with assets and examine how thing are put together.

The interface was also fairly similar to animation software such as 3D studio Max and Maya so it was easy to get started in the basics, such as moving in the environment, moving objects and changing textures.

Documentation about all game engine functions is available on the internet, and game developers have also made several video tutorials that are available in the CryEngine forum and on YouTube. The forum includes most issues, and new questions can be asked as well. These elements are important for an introduction to a game engine and provide a platform of knowledge that makes it possible to explore new ideas.

The game engine had the ability to not only simulate real-time environments in a game mode but also to use this function in the editing mode. This provided new possibilities in relation to design because it enabled the possibility to run a system in real-time and simultaneously change it. The impact that this may have when using the tool in collaborative design sessions was uncertain and it could only be tested through real-world design projects.

Exploring game engines in collaborative design sessions

Through several collaborative design sessions, I tested the game engine functionalities as a design tool, mediation tool and simulation tool as part of action research and research by design.

As an introductory and pilot case, I used an architectural urban design project of the development of a new harbour area in Uddevalla in Sweden that was led by the Markis EU network. The aim was to use the SimSam-lab and the game engine to facilitate the discussion about the design challenges and to visualise the design solutions. There were several actors involved, such as politicians, architects, engineers, urban planners, industries and other interest groups from the Uddevalla community.

By using the game engine, I then visualized four design concepts and simulated the sea level height to facilitate the discussion between the participants (Figure 24).

Figure 24. Picture taken during the collaborative design session showing the initial process in which the commune urban planner explained the existing challenges of the area. From the desk on the left side the scenario can be controlled like moving the camera or adding and moving 3D objects.

The process began with a meeting with the Uddevalla commune discussing the possibilities of using SimSam for a collaborative design session. Their need was to create a representation that was dynamic with the possibility to change the landscape and add and position objects during the session. They also wanted to represent four solutions on a similar abstraction level. In this initial meeting, they also brought an architect who developed two concepts based on the commune plans (Figure 25), and there was also a commercial architect concept and a concept based on a floating island from Vestfold University College (Figure 26).

Figure 25. Frame from the game engine showing the commune concept of keeping some of the old industrial buildings in the area and combining them with new apartment buildings.

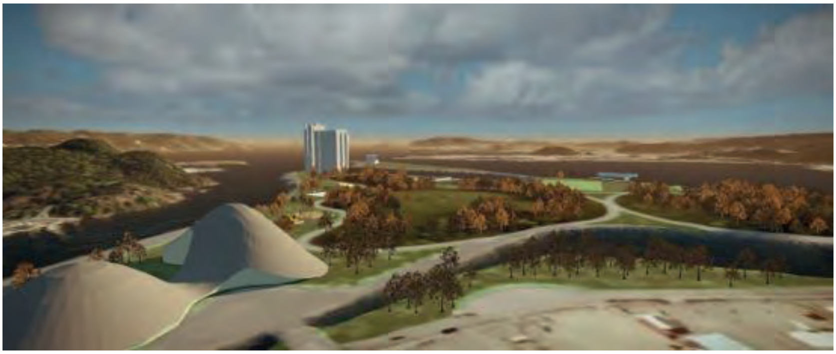

Figure 26. Frame from the game engine showing the park concept mixing several concepts into a new concept. Grass and trees was painted into the landscape and it was possible to experience the park from a first person view.

Use of real world data in practice

I imported the landscape model based on GIS data into the game engine and measured dimensions and highs to verify the model using maps provided by the Uddevalla commune. Through my research, I have found that it is possible to model environments in game engines that are based on information from the real world using several sources and different types of media. Through the use of GIS data and SOSI formats, it is possible to convert DEM elevation data and texture it with high-resolution photos taken from airplanes.

I could also import structural information, such as entire cities and road networks, based on auto-generated 3D files from a SOSI format. All of this data was provided by the governmental map office (Kartverket) that is continuously updating this data based on resolutions and new urban structures. It took some time to find the right workflow to convert the height maps and the ground photos for the game engine to accept the formats and generate the right resolution and accuracy. The process for elevation maps was: 1) Download raw data, 2) Assemble multiple files using Global Mapper software, 3) Fix digital artefacts in Adobe Photoshop, 4) Import and enter the right elevation scale in World Machine terrain software and export it using the right format, 5) Import in game engine. The ground photos can be edited in Photoshop to provide colours and then can be exported as segments. If it is not exported in segments, a 30x30km map will need a 1000 megapixel picture that uses around 200GB on a hard drive.

The use of real-world data enabled participants to recognize elements existing in the real world at a high-detailed level. It also created accurate contextual boundary conditions in which the design of new structures and simulations of scenarios take place. The elevation accuracy was limited to

1m in the Uddevalla case, and this became an issue when using the avatar mode with a first person eye height of 170cm from the ground. This issue dealt with the data resolution; however, it was possible that some places would get laser scans with up to 100 points m2. The challenge with this data is that it may have been too accurate in taking time to edit objects that are not part of the terrain.

Importing architecture

After the terrain was imported and textured, I began working on the 3D models. The initial reason I selected the game engine as a tool for this project was the ability to use the CryEngine PlayUp plugin in SketchUp to directly export 3D objects and textures into the game engine. Because the Uddevalla commune and the architect company had already created their model in SketchUp, I made the decision along with the Uddevalla architect to use the game engine in the collaborative design session in SimSam. When exporting the model to the CryEngine object directory, it would pop-up in the entity list after hitting the refresh button in the engine. By this, I discovered that it was possible to import new objects in to the game engine from external software without restarting the engine.

I tested this function with the use of the open 3D model internet library Google Warehouse, using it to download a cruise ship, and directly imported it into the game engine in less than two minutes. This opened the possibility to use Google Warehouse during collaborative design sessions, giving the actors the possibility to suggest adding new 3D objects into the scene.

Facilitating the collaborative design session in a real-time game engine editor environment

During the collaborative design session in the SimSam-lab, I first used the game engine to explore the existing harbour area in Uddevalla to discuss social settings, industry, pollution and flooding. We used the engine first for a top view as a standard map and then moved closer to look at industrial buildings and then to a first person's view. I had the role of navigating the game engine, while someone discussed a specific subject. To illustrate the flooding, I increased the sea level and adjusted the sea texture. The participants could immediately associate the representation with the real world. We continued the session by presenting the different concepts and discussing solutions. Because all buildings were placed in different layers, it was possible to mix objects from different concepts to generate and facilitate new ideas.

Summary and findings

Through this initial study, I explored the game engine technology and workflow as mediation and a design tool in a collaborative design session. I learned about how to prepare the engine for the design session, workflow with external partners, implementing real-world data, modelling a terrain, importing objects and textures, the use of Google Warehouse, navigation and object manipulation during the collaborative design sessions. Because I had a close collaboration with the commune architect during the preparation stages of the project, he was able to use the game engine for further design sessions in Uddevalla. The commune also had plans for using the game engine in a public exhibition in Uddevalla to create a public discussion.

Dynamic real-time simulation using game engines

When behaviours and actions between objects and users are simulated over time, they provide different types of information and insight into what they are and how they react to interaction. I have used simulation in several different ways to create an environment in which events and scenarios can grow, evolve and change based on direct input. Simulations are used in direct and indirect ways when applied in these user studies. I have used simulations to mimic behaviours of users and systems in context over time using a game engine as a mediation tool. These behaviours can be described as 3D objects or entity properties that can be triggered by interacting with other 3D objects or entities. An entity can be described as a dummy object that does not need to have a physical form; it can exist as a boundary condition.

The game engine objects and entities were programed using C++, LUA or XML coding, which is often restricted to expert programmers; however, the CryEngine has a script GUI editor called FlowGraph in which scripts can be linked, edited and connected to 3D objects and entities in a schematic view (Figure 27). Several pre-made scripts are available, making it possible for non-programmer experts to design behaviours and scenario actions.

Modelling actions

The FlowGraph (Figure 27) shows how actions and behaviours are combined to simulate a helicopter-landing scenario used in the process of designing a helideck light system. The scenario must be set up like this: 1) When the simulation starts, the helicopter pilot artificial intelligence (AI) and passenger AI will enter the helicopter. 2) It will then find its way to a pre-made flight path and follow this path while adjusting its height, angle and speed. 3) When it has reached its path end, the helicopter will stop moving, the passenger will exit and the gate lead lights will automatically be switched on. 4) The passenger will find its way to its pre-modelled walk path and follow it to the living quarters.

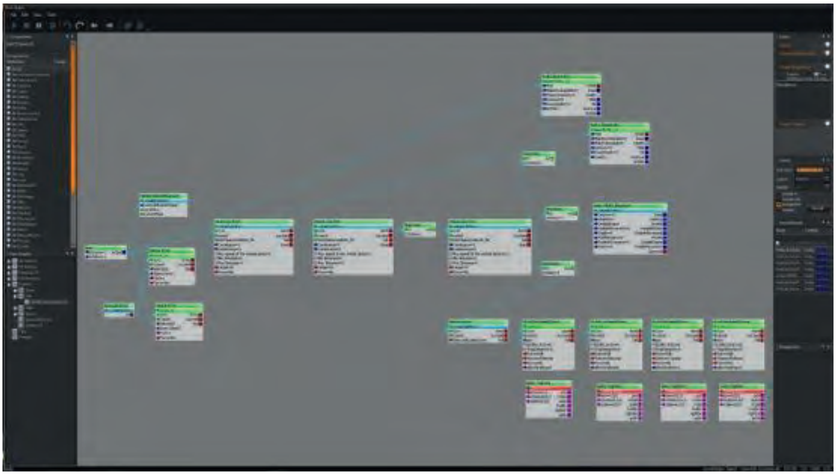

Figure 27. Screen capture from a game engine helicopter-landing scenario in FlowGraph. There are similarities in the node design interface in the game engine and the CSCW simulation model, GUI. Each of the boxes is linked to the 3D objects and control them. The blue lines connect the scenario logic.

This simulation was based on triggering mechanisms to trigger new predefined actions. An action or behaviour such as a human AI may always have two or more outputs to 'succeed' or 'fail', and this means that if a new behaviour is added that intersect a series of events, it may not archive its goal and generate a fail output. This fail output may then be used to restart the events in what is called a loop mechanism, or it may trigger new behaviours (Figure 28). The interesting perspective in this is its scalability. It is possible to have several behaviour mechanism systems within the same virtual environment that behave in isolation or interact with each other to begin a series of new actions and events. Being able to simulate several systems simultaneously provides the ability to address complexities with human-in-the-loop simulations, which go beyond any previous approach in UCD when studying users in complex and critical contexts.

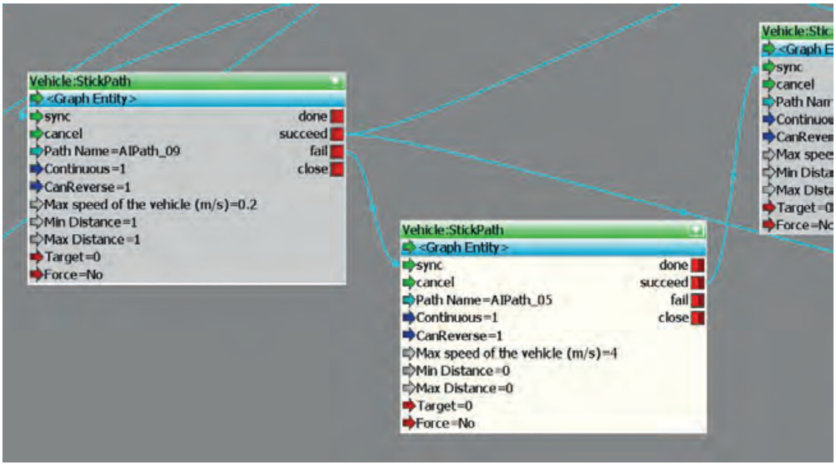

Figure 28. Screen capture from the FlowGraph with fail output loop. If the initial task does not succeed, it will receive the fail output, triggering a new action.

Modelling behaviours

In the virtual environment provided through game engines, several forms of simulations may exist simultaneously. I have described the use of behaviour-triggered simulations. Mathematical calculated models can also be integrated in these same events and scenarios. In my research, I have used physics to mimic ship movements adjusting its mass and centre of gravity in relation to buoyancy, or I mimicked light emission or collision detection (Figure 29). The simulations are not modelled to be accurate or to test the physics, but they are used to mimic physical behaviours that are approximately how they would behave in real life to co-create an impression of how situations may be experienced.

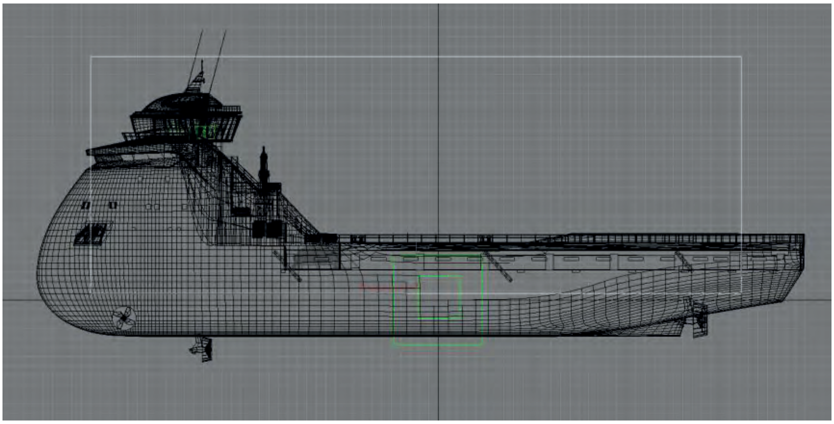

Figure 29. Screen capture of a ship model in 3DStudio Max. The white line indicates the hull proxy box that defines object volume and mass. The green boxes are dummies placed in the object centre position connecting the model to the XML and LUA scripts.

By adding human AI to the scenarios through a game engine *flow-graph* script, it was possible to create stories in which the AI interacted automatically according to its programmed parameters (Figur 30). This is part of the modelled system that is simulated. These flow-graphs can be designed to react to changes in the scenario and act accordingly. For example, it was possible to make the characters follow tag points and avoid collisions with objects. It was also possible to trigger actions for both AIs and avatars. This means that action can trigger decisions on new actions within the system. This can be used to replicate real-world roles.

Figure 30. Frame from a video of a collaborative design session described in publication 3 and 4. Pathways for AI were used in the Oslo Fjord crisis simulation scenario that is possible to see on the screen.

Importing complex 3D objects

Game engines such as CryEngine often have their own 3D file formats. In CryEngine, files must be exported from animation software, such as 3DStudioMax or Maya. I have had several issues when trying to convert the 3D objects and have them exported to the 3D structure. One of the main issues is that 3D objects used in real-time applications are often optimized for faster rendering times. This is in constant focus when game developers are modelling 3D objects and makes the process of converting models from design construction software more complicated.

3D objects that are meant for animation or traditional ray-tracing do not require the same level of accuracy in geometrical structures. These are the main issues I encountered with the Ulstein PSV ship: point in space, point closer than 1mm, fatten UVs, scale, xForms, all objects must have less than 64000 polygons and all objects with collision detection must be less than 10000 polygons. The restrictions of polygons require a schematic setup linking all parts to a dummy. A 3D object with functions or physics, such as AI and vehicles named ‘dummy’ linking the scripts, must be added to the 3D file. Proxy 3D objects also need to be added for physical interaction, mass position and centre of gravity. In our use of the game engine, the exportation workflow created the most issues and required the longest time to work out.

Simulation models for contextual exploration

Contextual reactions in this scenario simulation approach not only included the user situation but also the system of contextual relations that can have an influence on the scenario being explored. The context creates the boundary conditions that set the premises for all aspects concerning the user situation. By changing a scenario, the contextual relations will also change, and then changing the context may influence the user situation.

When preparing the simulated scenario for collaborative design sessions, the model was prepared to be changed. This means that different techniques were used to keep the model ready for change based on the factors. For the helideck light system scenario, for example, I created layers of light that could be turned off and on to see the different effects. Because the layers could be isolated, it was very easy to change other parameters, such as one hundred light sources at the same time. I also added elements that may naturally exist in a situation to mimic real-world conditions (Figure 31). Sometimes, these elements do not directly affect the scenarios, but they may play a role when the scenarios are iterated.

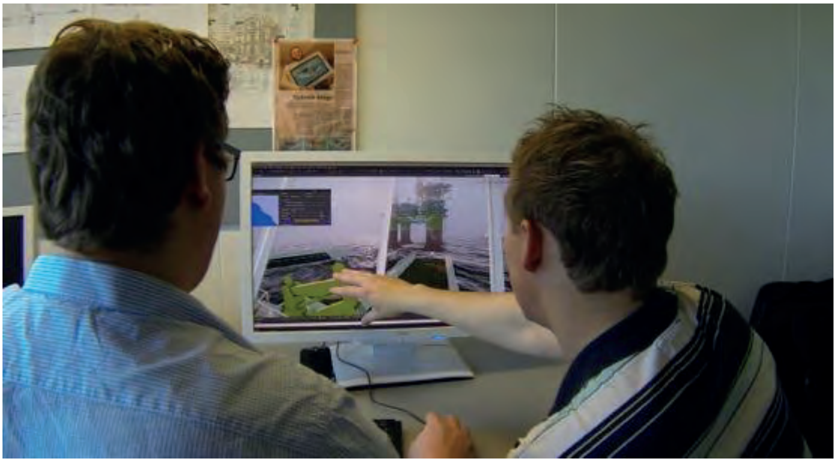

Figure 31. Frame from a video of a collaborative design session. Fog is added to the scenario, and the user reflects on possible implications.

This is a session described when modifying the contextual relations of fog with the supply vessel scenario described in publications 4 Design and computer simulated user scenarios:

> The DPO argued that the wind is a critical element that that is always given close attention. We then added a 10 m/s wind to the scenario, and we could see the vessel starting to move toward the rig. The DPO argued that he always tries to have the same heading as the rig and stay on the off-drift areas to prevent collision should they lose control of the boat. It is also important to keep an eye on the anchor chains. (Hjelseth et al., 2015:12)

Modes of collaboration and participation

Through the collaborative design sessions using dynamic simulations of scenarios, such as ship traffic, dynamic positioning in icy conditions and helicopter rig landings described in publication 4, I have found several different modes of collaboration and participation. During the design sessions, it was important to focus on the scenarios as operation and contextual relations to systems and tasks. I have not focused on user and actor interactions with the computer interface for collaboration and participation, as I believe this creates a focus on the performance of interface use. As a designer and facilitator, I have worked as an extension on verbal communication from the users and actors involved, exploring and changing the scenarios according to the discursive process. Through this process, I have experimented using different types of modes of collaboration and participation.

The modelling mode (Figure 32) can be described as a static simulation in which the game engine produces real-time renderings of 3D-models with textures in the game engine editor. It is possible to move in the virtual environment and explore the scene setting. In this mode, it is possible to model the scenario by importing 3D objects and entities and changing the environment. In the collaborative sessions, I used this mode to describe a scenario before applying dynamic simulation techniques to create a shared understanding of a scenario. This mode is also used to describe the static state of individual objects and enables the users and actors to participate in modelling the simulation.

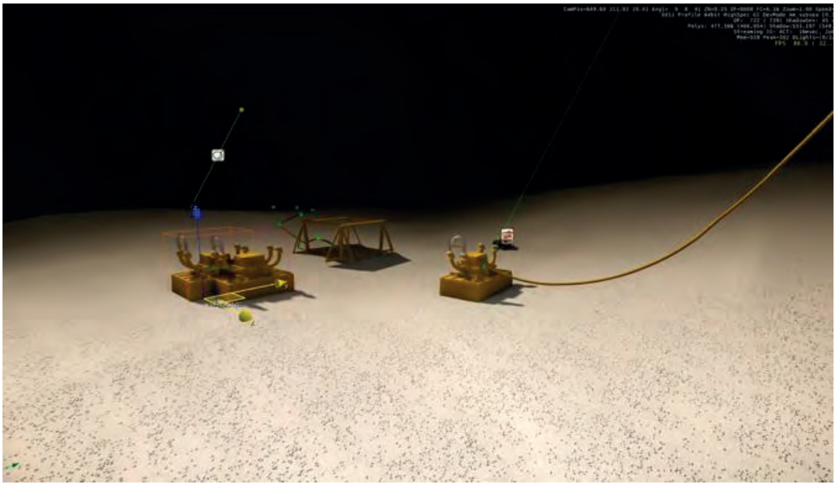

Figure 32. Screenshot from a gem engine in modelling mode of a subsea scenario. The picture show how a subsea manifold is copied and placed on the sea floor as an example on how a scenario can be modelled.

In Simulation mode (Figure 33), all simulation systems running trigger actions and behaviours that are programmed into the simulation scenario. Users and actors participating in the session reflect on the scenario that is evolving in time through a third person free-movement perspective, observing as the situation unfolds. In this mode, it is still possible to add and change the scene settings, such as adding objects and changing the environment, as the simulation is running. This enables not only reflection in action but also change-in-action improvising in real-time.

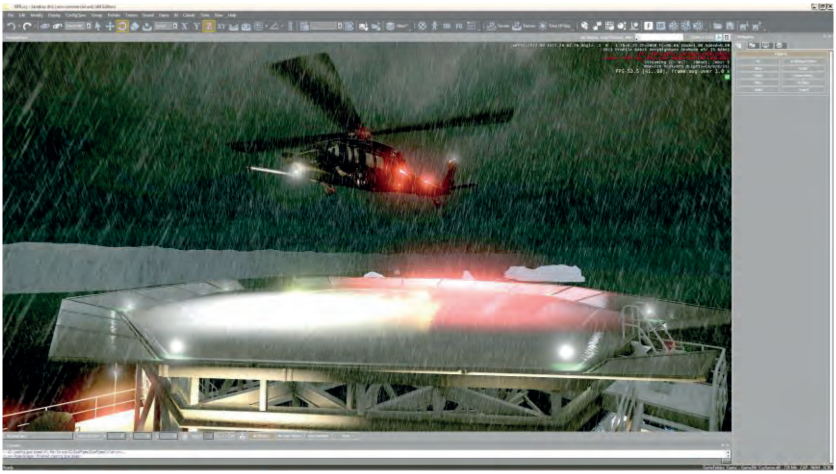

Figure 33. Screenshot from the helicopter landing described in publication 4. The scenario runs in simulation mode, which runs the action scripts of landing the helicopter.

In Avatar mode (Figure 34), direct participation in the simulation is done through an avatar. In this mode, the view angle is in the first person and represents the situation from the user's view perspective. The avatar can interact with the scenario, improvising new actions or behaviours. This mode builds on game theories and is represented in other UCD processes as a method of testing and evaluating designs.

Figure 34. Screenshot from a game engine of the Ulstein Bridge Vision concept from the bridge at night. A first person perspective is used in avatar mode to get an impression of how the scenario can be experienced by a user to discuss how the bridge should be used at nighttime.

Users and actors often use previous real-life experiences and events in this process to reflect on the scenarios. When the scenario simulations change according to this input, it creates an iterative process, shifting between existing situations into future scenarios. This explorative approach creates revealing situations in which new issues or solutions become explicit. In this process, unexpected situations sometimes occur because of the dynamic simulations effect on the real-time input.

When modelling actions and behaviours using scenario simulations, I have found that object behaviours can be specified in detail regarding how they should behave in real-time. In the helideck light system scenario, it was possible to adjust how the light should behave in accordance with time and events.

Summary and findings

In this chapter, I describe the research approach used to explore the use of simulated user scenarios in collaborative design sessions to facilitate conceptualisation in the maritime sector. Action research and research by design are the two main methods used in combination with design case studies of commercial design projects in the maritime industry.
The cases began by exploring challenges when doing UCD in critical and demanding operations of seismic streamer recovery operations. In this case, I found that traditional design and task analysis approaches can become too complex in handling large amounts of information. It can then be a challenge to create a shared holistic understanding of the operation between interdisciplinary actors involved in the design process.

Through the Uddevalla harbour case, I explored the use of the game engine CryEngine to create a platform to experience design concepts in a real-time virtual environment. I found that the game engine has similar workflow patterns as the 3D tools designers already used for construction and animation. The concepts could be explored in a collaborative design session by project actors through a facilitator navigating in a virtual environment. It was also possible to co-create new concepts during the design sessions and to import new models using Google Warehouse. The final part of this chapter explains how scenario simulations are modelled and how it is possible to apply simulation in different development modes. Publication 3 and 4 describe more of the cases used to explore the simulation techniques and functions.

Chapter 4: Reflecting on Simulation in and through Design

This chapter draws together the earlier material presented from published research, contextual knowledge and consultation by way of professional maritime work, and my own design practice and practice based exploratory research inquiry. I converge these various aspects and insights to reflect further on what may be advanced in interdisciplinary design based research to answer to my core research question: How can new approaches through simulation be developed to answer the challenges of UCD in the front end of maritime innovation?

In reflecting on simulation in design, the chapter has four main parts. The first concerns the exploration of three core concepts, the second the outline of a process model, the third a summary of research findings and fourth a discussion of implication for design and research

First, the chapter takes up the challenges of UCD in the early and reflexive conceptual space of design in this context by proposing a *design centred view on simulation* described in concept 1 based on gamification and real-time that I believe are important when simulating scenarios to facilitate design conceptualisation in collaborative design sessions in the front end of maritime innovation. The three concepts are named as follows: 1) Simulation and conceptual design, 2) Game engines and scenario simulation, and 3) Real-time scenario modelling.

Based on these concepts, I next suggest a model for addressing the role of game engines in meeting the challenges of visualisation and simulation in UCD in the sector. I label this the *Contextual Simulation Process Model* and *Contextual Simulation Space Model*. Proposed is theoretical models that describes the complex, unfolding and dynamic processes of using simulation in game engines to conceptualise UCD processes in collaborative design sessions.

Third, concerning the development of a design centred view on simulation, these three scenario oriented concepts and the contextual approach to simulation process allow us to look beyond traditional approaches to conceptualisation within the maritime domain. I discuss the three concepts and the *Contextual Simulation* models as findings.

Fourth, the chapter closes with discussion of findings and direction of the research, possible new routes to investigate and wider implications of the research for design practice and for further research. Simulation is becoming far more important in UCD directions because new technology allows more human immersed experiences through VR that is very interesting in design work because it allows design concepts to be experienced and interacted with in new ways. However, the main challenge to incorporate these technologies into design practice requires tools and methodology that I have addressed in this thesis and this chapter takes these up analytically.

CONCEPTS FOR SIMULATION IN DESIGN

Through the research presented in this thesis on simulation practice in design by ways of several case studies, I have found that simulation indeed does need to be closely connected to design practice and research. My main argument for using simulation in a UCD view is to find methods and tools that allows design to answer the challenges in designing for user in the maritime sector. In a broad perspective, design can be described as a process of '…changing existing situations into preferred ones' (Simon, 1996:111) and that UCD is '…an approach to design that grounds the process in information about the people who will use the product. UCD processes focus on users through the planning, design and development of a product' (Usability Professionals' Association, 2014). This renders design also responsible for understanding the existing situations before they are changed, the actual transformation process of changing, and the changed situation.

I believe that simulation offers design a new approach for understanding the relations between existing situations and future ones by allowing real-time change in design time. However, as the maritime domain is very complex in terms of operation, systems and contextual implications, it can be very difficult to establish whether the changed situation is the preferred one, since many of the problems are ill-defined. The approach to solving UCD problems often requires other methods than linear thinking because the problems are often referred to as 'ill-defined' (Lawson, 2006; Lowson & Dorst, 2009) or 'wicked' or 'unwieldy' (Rittel et al, 1973). There is a gap between how to use simulation for such ill-defined and wicked problems because traditional simulation techniques are often based on solving problems using analytical thinking only. Winsberg (2010) describes several approaches to such analytical simulation where the main focus is to verify and validate the simulation model and processes. This thesis has developed an alternative to this in the form of an exploratory design-centred view on simulation.

In this section I offer reflections on such a design-oriented view on simulation that describes how to approach simulation as part of a UCD practice. This view presents how this approach covers the gap between simulation and design problems. I also see this as part of a larger multidisciplinary aspect of the gap between maritime innovation processes and UCD where the simulation tool has the key functions of a hybrid design space and media platform. The design space that Schön (1983:157) describes as virtual worlds connects the interaction of the designer and virtual space were the designer imagines design problems, situations and tests hypothesis based on learned knowledge and experiences of the design situation. I refer to this design space not just as an individual imagined space, but also a shared imagined problem and solution space between design process and participants that can be materialised through boundary objects. I build this approach by drawing on participatory design research (Asaro, 2000) that identifies the importance of user involvement when designing for users and work (Bannon, 1993) where the learning artefacts we describe as boundary objects (Star & Griesemer, 1989) becomes central for design, collaboration.

Scenarios as boundary objects may be developed and understood as a method that connects simulation and UCD providing a perspective on what simulation has to offer design. Scenarios offer specific settings and situations as a basis for communication between actors, users and designers (Bødker, 2000). Scenarios have also the function of revealing possible solutions and problems (Dorst & Cross, 2001). However, there are few design tools that offer a specific time based approaches interacting with scenarios in such multidisciplinary settings as the maritime ones included in this thesis. This setting requires reflection-in-action where ill-defined and wicked problems are constantly framed and re-framed as part of a discursive process (Schön, 1983). I have found that simulation offers the ability to interact with time critical events and behaviours where actions can be iterated and evolved, and that simulation can be used to mimic real world elements such as wind, gravity, sea waves, etc. Game engines as simulation tools allows us to visualise scenarios, they provide us an interface to interact with them and function as a platform to combine different types of media so as to model the scenarios. I have found that this scenario simulation technique enables a design setting to be developed that is contextually situated to address user needs and experiences of systems, operation and tasks in an interdisciplinary design setting.

In order to further analyse these perspectives I propose three concepts that I believe are important when simulating scenarios to facilitate design conceptualisation in collaborative design sessions in the front end of maritime innovation. *Concept 1:* I call this Simulation and Conceptual Design. This describes a *design-centred view on simulation* that argues how conceptual design can use simulation techniques in the design process with a different perspective to the traditional simulation focus on verification and validation, using simulation as a test method. *Concept 2:* Game Engines and Scenario Simulation. It addresses the use of game engines as scenario simulation and modelling tools and creates a platform to mix different types of media into holistic systems and scenarios. *Concept 3:* Real-Time scenario modeling. It deals with real-time scenario modelling in collaborative design sessions that facilitates participation and a reflection-in-action process.

Concept 1: Simulation and conceptual design

The use of digital computers to study phenomena and complexity through computer simulation has seen astonishing growth and has had implications in almost every scientific study. UCD practice and research has provided very little evidence on how it has been utilized and if it is beneficial. Expertise in computer simulations theory seems to be limited to fields with a strong relation to mathematics. The traditional scientific function of simulation was about conducting scientific experiments on a computer as a process of knowledge creation (Winsberg, 2010:6). In science, the epistemology issue in simulation deals with its ability to study phenomena providing trustworthy data that can be validated and verified (Winsberg, 2010:9). Computer simulation, e.g. physical science, is pointless if it is unable to imitate the real world and lacks validation and verification; it is based on the principles of technical rationality. Because design epistemology largely deals with 'how things ought to be', it needs to approach knowledge creation in a different way to natural science that focuses on 'how things are' (Simon, 1969:4).

The traditional natural science approach in simulation uses reduction techniques that try to isolate problems. This is different from design techniques that shift between convergent and divergent exploration (Lawson, 2006) in the fuzzy front end of innovation. It is important that UCD has its own view on how simulation should be applied to its domain because the fundamental approaches to solving problems are different to other sciences. I call this *a design-centred view on simulation:* I define this as follows: a *design-centred view on simulation* is about modelling and simulating behaviours and actions of user scenarios in systems task, operation and context with the goal of exploring and revealing implications for design.

Simulation taxonomy in design

I frame a *design-centred view on simulation* through looking at the basic structures on simulation taxonomy from the natural sciences because they classify the basic groups of simulation types. By using the different classifications of simulation, it is possible to translate it to a *design-oriented view on simulation* that gives designers the ability to articulate its meaning when used in discussion. By situating computer simulation in design practice, it is possible to further distinguish between different types of simulation, such as static, dynamic, continuous and deterministic (Birta & Arbez, 2007:21; Özgün & Barlas, 2009).

Static simulation in design can be described as mimicking the real world without any evolution. Pictures, 3D objects, animations and films are examples of static simulations. However, in some fields, this type of simulation is not seen as simulation because it is not self-evolving.

Dynamic simulation in design involves systems that evolve based on their structure and connections. Improvised role-play is a dynamic approach; however, it is also stochastic because human-in-the-loop input provides variable random input with different outputs for the same scenario.

Scenarios that are simulated using game engines can provide a dynamic simulation that is also deterministic because it can reproduce evolution through mathematical systems. This means that iterations can be done by controlling the known input factors. The simulation can also be stochastic when it is based on the use equations that produce random output or human-in-the-loop integrations through avatars and real-time editing.

Ill-structured simulations

Applying traditional simulation theory and techniques in UCD will not solve ill-defined design problems because their nature is different based on rational analytical problem structures. Design deals with a process of diverging problem spaces that create new choices (Brown, 2009). A design-oriented view on simulation uses diverging techniques to explore relations of evolving systems in a design phase, where the innovation starting point and goals are fuzzy.

When factors are unknown, ill-structured boundary objects are created. However, it might not be possible to verify or validate all input factors that are impossible to solve. Using a design-oriented view on simulation, it is possible to use the simulation tools to model the simulation based on user experience input from real-world experiences. Therefore, it is possible to apply new suggestions in the model regarding how things might behave and evolve.

Experience-based simulation modelling

An example of experience-based simulation modelling is a physics simulation I created in the early stages of our research. I used the fluid dynamic simulation software RealFlow to mimic bouncy balls (see figure 10). To do this, I did not fill in the exact material values of a polymer but rather, through trials, I explored how I perceived the soft body dynamics based on previous experiences with bouncy balls. This type of simulation technique might not be of interest to material scientists, but in UCD, I can hold a discussion on a subjective level about how I like bouncy balls to be experienced.

Simulating such isolated events might be useful for designing specific experiences or interactions; however, it does not provide the means to model and mediate phenomena on more complex levels between people, objects, technology, activities, contexts and culture that are critical in user-centred design. To design with such interdisciplinary factors often required in UCD, we need to look at approaches that can investigate all of the connections and relations. The use of scenarios is such an approach.

Simulation as reflection-in and by action

The point of introducing simulation to UCD is not to test for performance or to provide proof. A design-oriented view on simulation provides a solution space for exploration to reveal issues, challenges, solution and possibilities. The simulation can be seen as a boundary object, where reflection-in-action happens through change and in trying to understand a situation in a process of reframing (Schön, 1984:132). Through this process, the problem and solution evolve through interaction with the object. In contrast to more traditional design tools, like drawing, all the changes made to the material are carried out manually and controlled by the reflection in that moment. When using computer simulation, the simulation model controls the evolution in which results might yet be unexpected. The simulation model is iterated. This is based on the traditional sense of reflection-in-action and reframing, but parts of the material complexity are simulated using a computer. However, in my research, I have used a real-time simulation that allows the simulation model to be changed during simulation. This means that the reflective and changing process is happening in the simulation action space in real time.

Concept 2: Game engines and scenario simulation

My approach to maritime innovation is to explore the relations and activities between the context, system and users. Such exploration can be done in many different ways, such as mapping its information in giga-maps, task analysis in float diagrams or using simulators for testing systems and usability. Scenarios are used in all these approaches to generalise ‘stories about people and their activities ...’ (Carroll, 2000:46). Such scenarios are often modelled on ‘what we know’, whereas design deals with ‘how things ought to be’ (Cross, 1982), which means creating stories about people and their activities. Play and game design offer a framework for such scenario enactment and construction. Game technology in the form of game engines offers a collaborative and participatory platform for sharing different types of media to construct scenarios of context, systems and users that can be simulated using a design-oriented view on simulation. This can be described as gamification that uses game design and technology to include users' experiences in non-game processes (Deterding et al., 2011). Gamification in UCD can be defined as offering a process and tool when creating a boundary object using game engines. It provides a platform to mix several types of media to shape a holistic perspective through scenarios in the process of understanding user needs and experiences.

Game engines as media platforms

Part of design practice is to work with the overall and holistic picture of a situation, which I do because I believe that the relation between all elements is needed to fully understand its implications. As described, designers deal with this complexity using several forms of digital media to create the representations needed for reflection. Visualisations, 3D models, animations, video, interaction, logic, textures, mechanics, sound, motion capture, text, web-content and simulations are some of the forms and materials used to express and explore the design space. Through these, designers can shape systems, contexts, behaviours, tasks and scenarios that hold the holistic perspective and connect all these elements.

Game design in scenario simulation

By using computer game design concepts, I have been able to build on functions that allow scenarios to be evolved and iterated through exploration. *Computer plasticity* is the ability to experience virtual environments with no restriction to dimensions and scale. Functions such as *real-time play* provide the ability to simulate and visualise scenarios in real clock time. An *Intelligent opponent* is AI technology that simulates human behaviour, which uses human logic and behaviour as scenario factors. Such game functions enable on-the-fly creation of embedded and emergent narratives in developing new scenarios (Wei, 2010).

Game engines as tools to design user experiences in context

Because game engines are initially designed to create user experiences of situations that mimic real-world factors to create narratives, they also provide an efficient tool to design future user situations in scenarios. These scenarios can be experienced in a collective setting and modified, allows us to create a setting for *exploratory play* and *construction play* (Brown, 2013).

Concept 3: Real-Time scenario modeling

Simulating user scenarios allows mediation of behaviours between the context, system and users in an evolving dynamic time space. Scenario simulation as a boundary object is constantly changing, based on simulation and actor input. This real-time function creates a notion of an immersed tangible presence in a situated virtual environment (Sanchez-Vives & Slater, 2005). This co-existing virtual dimension becomes a space for learning and exploration that facilitate the process of reflection-in-action through co-creation (Sanders & Stappers, 2008) and collective creativity (Sanders & Rim, 2001). The concept of real time in USD scenario simulation can be defined as the real-time dimension of simulation of user scenarios using game engines connects the process of reflection-in-action in collaborative design sessions.

Design tools for evolution and time

Another area to examine is how time is used as an element in design. Traditional design processes have very few tools and methods that integrate time in detail as part of concept development. Using visual storytelling with image sequences, animations and interaction sketching techniques (Buxton, 2007), designers are able to shape behaviours and interactions in time. However, most of these design tools and techniques provide fairly abstract representations, and the evolution and time elements have less focus. Through the real-time virtual environment in game engines, time becomes part of the boundary object and can be experienced though the evolution of simulated scenarios.

Real-time editing

Game engines such as CryEngine from CryTek use real-time game design editors to provide a faster and more immersed workflow when designing the game experience. All logic, simulations, behaviours and visualisations are mediated in real time and can be changed in real time. This real-time global virtual environment creates a notion of a second dimension of space and time imitation of our real world. The possibility of expectancy created by real-time simulation creates revealing moments based on direct input. The dynamic continues output from scenarios in real-time simulation creates questions about elements that can only be experienced through time, and because the game engine editor is in real time, it is possible to change it during the simulation. This creates an iterative feedback loop enabling the design to be focussed on specific design problems or challenges.

Real-time collaboration and participation

Through a discursive collaborative process between parties to the simulation, real-world user events from real situations are transformed into a digital material that is simulated in real time. My concept of real time exists in two simultaneous dimensions: the virtual real-time space and the design real-time space. These are part of the collaborative negotiation between the designer, actor and user. Because both dimensions exist in real time, and create a dynamic transaction of information exchange and reflection in action towards change in action, this instant collaborative workflow keeps the design activity focused and supports the notion of direct participation in a virtual space.

Discussion

This thesis focus on the core challenges of the maritime sector and how UCD can approach such challenges. These are challenges that exist in several layers that are connected to culture, user context and product complexity. Design is always going to find ways of doing processes better, faster and more efficiently. However, I have looked into totally new directions of facilitating core functions in the design process. Starting with research on visualisations, I arrive at a view of simulation in a design perspective. The central issue in this development has been finding methods and tools that combine collaboration and facilitate exploration as a boundary object that is connected to the time aspects of the problems being designed.

Issues and challenges in maritime design processes

The maritime sector might be seen as a very conservative one that makes small and incremental steps rather than giant radical leaps. Jenssen (2003) argues that the Norwegian maritime sector needs to focus on more radical innovation strategies to hold their current position in the global market.

Part on this process is to find better ways for collaboration between maritime companies and within companies. The products and services being developed need attention from several disciplines in order to solve both known and emergent design problems. For example in offshore ship design at Ulstein Design & Solitions they have several departments within that part of the company that is responsible for specific parts of the ship concept design. These departments are: naval architects, hydrodynamics, propulsion and power. The employees describe the collaboration process as chaotic and with little structure. However, Ulstein is one of the offshore shipyard companies that is seen as the most innovative in the market.

Another aspect of designing for the maritime sector are the risk and safety requirements directed towards users. Human failure, caused by a combination of organization, technology and the environment's incompatibility with human performance, is by far the largest contributor to maritime accidents (Rothblum, 2000; Bjørneseth et al., 2008; Grech et al., 2002). This is a problem that the industry is aware off, however there are several factors that contribute to this problem. Part of this problem is the collaboration process between actors. Innovation within the maritime domain also tends to be more technology-driven than focusing on users as part of innovation strategy. My own perspective is that there is a lack of both motivation and competence in terms of designing for users in the engineering culture that exists in the maritime sector. In the simulator development case (p.65), the main approach to solving the simulator design was conducted from a technological functional perspective. There was no motivation on the part of the engineers to conduct field studies in order to understand the operations from a user's perspective. I believe that the best way to approach the issue of human error in the maritime sector is to involve both industrial and interaction design in central roles in concept development. However, the challenge here is to understand how to introduce the UCD tradition so that it adds value to the existing engineering development and innovation process. To a very limited degree UCD is represented in the maritime sector (Hukkelås, 2013). Competencies used in maritime innovation processes are engineering based. In addition there is little training in designing for users. These aspects we have seen in the case study on page 67-68 where a simulator was developed. I believe the maritime domain needs UCD competence within their innovation loops in order to address the problem of accidents cased by humans.

The maritime context at sea has limited links to designers on-shore (Lurås, 2014; Mills, 2006). Most of the situations being designed for happen out at sea. This might result in design situations where the designers are not able to see the main problem of their design because they do not understand contextual implications. It can also be a challenge to understand operational situations in relation to human and system behaviour. I have found this to be demanding in several of the case studies. The challenge is often addressed by involving users in the design process. However as in the simulator case study in my research the mere presence of users might not solve this issue without additional elements such as video or models. An additional finding in this case was that observation material of offshore operation provided by users did not nessesarily focus on what is needed for design. To overcome this, as a researcher and designer, I conducted field studies to focus on the problems that needed attention. Lurås and Nordby (2014) describe this as design-driven field studies.

Hybrid and holistic design spaces

I argue that these design issues and challenges in the maritime sector need hybrid and holistic design spaces that can both maintain a technical rationality perspective and the user perspective in the same model and process. This can enable discursive processes where the direction of design focus can benefit from a shared space. This means that UCD must also implement understanding of how traditional engineering processes in the maritime domain are performed. Linder (2008) argued that there is a mutual lack of understanding and respect between industrial designers and the maritime domain of their individual processes. To overcome this challenge it is important to understand individual design goals and how they affect the product. For example, engineers need to know how the duty officer of the ship is manoeuvring it in order to solve issues. This is a process of negotiating situated knowledge and actions of work in relation to, for example designing systems for lower fuel consumption. Similarly designers need to be aware of technical constraints and systems when designing human interfaces that are safety and risk critical.

It is in such hybrid design settings that a holistic design space is needed. This is a space within which it is possible to hold several design perspectives in the same model. I see this holistic design space as a way of connecting all the elements that are relevant for existing and future situations. These include users, actors, tasks, operations, infrastructure, systems, technology and context. If a model can represent this holistic space it might also be possible to facilitate more effective and engaging interdisciplinary hybrid design interactions.

By connecting several design perspectives within the same holistic space it is possible to reveal connections that otherwise are not evident. When users from the maritime sector are involved in such design processes, it becomes very clear that this holistic perspective is very useful. This is because they argue from a user, task and operational perspective, but are also highly aware and professionally informed about technical implications related to tasks and operations.

Tools and methods for time based design

Another issue and challenge when designing for tasks and operations in the maritime sector is the element of time in design. This is because design tasks are task-, object system- and context-oriented. Being able to track interactions between users and systems is critical when designing for safety and risk critical operations. It might be minor time elements in the interaction that changes the understanding of a situation that might lead to accidents. This was the case, for example, in the helideck light system design when we did a test on implementing an automatic gate opener connected to the light system that gave directions on what gate to walk to after landing and that the deck was clear. We carried out several test on the time element between the timing of turning on the light and opening the gate. We found that the timing was critical in keeping the user aware about that the opening of the gate and the light were connected to ach other. If the gate was opened, the light would be turned on indicating the deck was clear for offloading passengers and gear. If the user would not be aware about the connection between the gate and lights, they might open the gate and indicate an all-clear deck without knowing it was in a critical situation.

Having a tool to model the time element in this case study was essential in order to understand its implications on design. This detail was also not identified as a design problem before the scenario was modelled. Design research has addressed this issue with time based design (Sevaldson, 2004) and found that there are several visualisation and analysis techniques that can be used to approach the issues of designing for and with time. Sevaldson argued that time based approaches help us to understand events, performance and lifecycles. This includes approaches such as how video techniques can be used to experience time and diagrams may be used to map instances and overlapping systems and actions in time. Still photo techniques used by Braun (1995) were used to study movement of objects by exposing several time stages in the same picture. Selvaldson (2004) also refers to a Flash simulation of user tasks, however it is not clear if the simulation runs based on a mathematical model of action scripts or if it is an animated visualisation. However, simulations are highly relevant for time based design because they enable a mathematical mechanism to control evolution and time.

Visser et al. (2005:135) argue that 'when important decisions have to be made, a clear and convincing argument can be made using a scenario of the interaction based on the design and the knowledge about its context.' In my research, scenarios play a role in all aspects of the design process. They are used to map what the designers know about a situation before it is studied. I therefore use scenarios to plan field studies on what is going to be researched and explored based on previous knowledge. They are used as a way of generalising events based on user experiences in design sessions and field studies. Scenarios are a way of creating a shared understanding between collaborative actors in framing problems. Such scenarios provide a setting in which to implement new factors in a situation and so also provide a setting to apply simulation models intended to evolve or mimic the behaviours and boundary conditions of future situations. In this way, scenarios may be a part of all design decisions, through all the different stages of conceptualisation.

Scenarios have proven to be a very efficient method to involve several types of knowledge on a shared platform, one that considers evolution and change as part of the design material. However, tools for constructing and visualising scenarios are not well described in design research. Scenarios are often described as frames in a sequence that have been developed based on what we know about existing situations. Bødker (2000) argues that scenarios materialised through crude models that do not actually match the real situation might lead evaluation of such situations astray. I believe that this is also dependent on the model being capable of communicating scenario infrastructures (Star, 1999), which are hidden in the use situation (e.g. steering the ship), and not only the objects details (e.g steering weel) that serve as boundary conditions.

Star and Griesemer (1989:408) argue that boundary objects are '…simultaneously concrete and abstract, specific and general, conventionalized and customized' and that shifts exist between structured and ill-structured states where the ill-structured boundary objects might be seen as incomplete or to have missing factors (Star, 2010)". For me, these states represent convergent and divergent moves in the design space, which allow ill-defined and severe problems that are not completely defined or that are missing factors to be framed as the problem and to be materialised through an object. However, I think it is important to be aware of the exact way in which the boundary object is ill-structured if it is to be used to trigger discussion.

By extension, there are several contextual factors that might have implications for scenarios. These contextual factors, for example, might be based on the physical laws of nature to design systems that are interacting with other systems that need to be tracked in order to create a realistic scenario model. Keeping such factors part of scenarios is a challenge because they are often to abstract and complex to be part of a cognitive scenarios construction process. It may also be that systems and data from other disciplines need to be integrated into a scenario that offer very time specific instances in relation to operation and user interaction with a system and context. Computational simulation offers such possibilities where the simulation model can mimic the system and human behaviour as part of an evolving, time-dependent scenario.

Simulation

Simulation offers UCD a totally new way of approaching challenges of learning, sharing and collaborating. This relates to understanding existing situations, but also in creating future scenarios on how things ought to be. Being able to mimic realistic settings in contexts through hi-fidelity visualisations becomes a great advantage for motiviating and sustaining user involvement. It offers the possibility to situate the discursive process of communicative exchange, understanding and action between designer and user in the context of use. This not only brings up the explicit sharing of knowledge, but it also become a process of infrastructuring (Star, 1996) that supports the understanding of hidden structures in situations or scenarios.

My approach to simulation in UCD uses game engines is to model and simulate scenarios that are constructed in virtual environments. Much of the modelling of the simulation is executed in the real-time virtual environment that also serves the visualisation techniques used to represent the simulation. In addition, my approach to simulation in UCD has also been developed through paying attention to the complexity issues and design challenges in settings of work and safety critical conditions in the maritime sector. This has allowed me to place design-based development of knowledge in work settings and in dialogues with experts, users and other designers.

Ehn (2008) questions how 'use before use' in design can be approached by designing in 'use time' and not only 'project time'. If I apply this concept to design for maritime operations it may refer not only to the object oriented perspective on industrial design practice, but also to contextual implications of use. However, it is very difficult to situate design for maritime operation in 'use time'. By visualising the context and simulating behaviours and systems it is possible to create a design setting that provides an immersed experience of being in context. This also enables the design to be situated in that context.

Such an approach in using simulation in design is about creating models and systems that can mimic real world conditions. Through design and exploration new factors are added that change the simulated scenario. The experience of the environment is verified and validated through user input and participation. The goal of the simulation is not to generate numerical outputs for analysis, but to raise questions about settings that have implications for design in 'use time'. In this way, the design object - as what is to be designed - might not be the goal for the simulation, but rather work as a critical artefact (Bowen, 2009) to be observed and explored to reveal new issues and possibilities for design.

There are examples on how simulation might be used in design, but the design research literature does not raise what simulation is actually doing for UCD and what it means for design practice. To do this it is important in order to describe some of the material properties of simulation and how this affects its function as boundary object in a collaborative design discourse. Turkle (2009) describes some implications for simulation in design, however she does not describe what simulation is or position it in design. To describe some of these material properties of simulation it is important to chart what simulation do for design. It may facilitate change and evolution in scenarios and supports interactions between systems. In addition, it provides a method to manipulate time. Finally, it uses mathematic to mimic the real world. Turkle (2009) argues that one of the pitfalls of simulation is that it creates seductive experiences through immersion, which might lead to situations where the designer is not aware of the simulation implications. I support such view, however I also believe that seduction of this nature can be a positive element when simulation is used in explorative conceptualisation as long as the rhetoric nature of the medium is acknowledged. This is because immersion allows one to believe in the presented situation, which can lead to the framing of problems in new ways.

Turkle (2009) also argues that designers should have complete control over their simulation model so that they do not end up in a situation where unknown factors in a black box produce the output results. I believe that this is dependent on what the simulation is to be used for. However, while it is preferable that the designer has full control, it cannot be expected, due to the general lack of programing competence. Therefore it is necessary for designers to be well aware of the potential limitation of a simulated scenario to avoid introduction of new simulator driven misconceptions.

I have used simulation to project and run behaviours, actions and events in constructing and exploring scenarios using as design method and boundary object for UCD in the maritime sector. Simulation has also been used to mimic real world conditions or object behaviours such as gravity, collision detection and buoyancy of ships. Game engines have been used as tool and framework to model the scenarios and implement the different simulation techniques. The game engine also becomes a platform to combine different types of media to construct these scenarios. As a platform it can facilitate both scenarios, from a user perspective and an engineering one, making it possible to combine ideas from both areas into a hybrid process that serves both engineering and user needs and interests.

Implications for design and research

I believe that the research presented in this thesis has implication for design research in several areas. UCD has difficulty in handling complex design challenges, such as described in the maritime sector. This results in a lack of trust and implementation of UCD in complex multidisciplinary design tasks. The research in this thesis shows how scenarios construction and exploration using simulation and game engines can provide a design space to approach such complexity. It can facilitate holistic settings that connect the relations between, users, tasks, systems, operation and context. This platform also becomes a place for collaboration and user involvement. It also provides a platform for a shared hybrid design process. So what does this mean for design research? I believe that simulation in UCD is one of the directions that will expand in coming years. Advances in Virtual Reality (VR) technology already provide one the biggest leaps in innovations. This will probably have a huge impact on design practice and design research. Simulation is one of the core functionalities used in VR, but design research lacks a basic understanding of its tradition of use, structure and taxonomies and how they relate to design practice. In advance of some of these developments, this thesis connects simulation and design research and explores their relation through design practice. This brings simulation into design research as a new way of approaching UCD in complex domains such as the maritime sector.

Toward a contextual simulation process

The three main concepts I covered earlier in the chapter point toward how to integrate simulation techniques and technology in a UCD perspective. Each concept contains elements that are critical when performing a design process from a holistic perspective. This perspective not only focuses on the defined design problem, but also on the contextual connection of relations that model a system. These concepts shape the foundation of the *Contextual Simulation Process Model* that describes an approach to using computer simulation in UCD. It is to this topic that I now turn.

THE CONTEXTUAL SIMULATION PROCESS

When researching the different cases presented in this thesis I found that it is very important to see simulation in UCD not as an isolated mechanism in a design process. Design tools connect to the physical space being in which the design is being carried out and to the cognitive and mental design space of problems and solutions. Boundary objects (Star & Griesemer, 1989) are what makes this connection between the different layers to make the discursive process that otherwise might be very abstract more explicit. In the maritime sector, it is necessary to involve users and multidisciplinary actors to design for high risk and safety critical situations where co-creativity and co-creation are central (Sanders & Stappers, 2008). This is especially important when problems and solutions are hidden in infrastructures that focus more on use and context rather than the object being designed (Star, 1996). Scenarios refers to events or situations about people and their activities (Carroll, 2000) and can be used to understand and study interactions between design and context (Visser et al, 2005). Through my applied inquiry, I have found that there is a need to describe and visualize the various elements that are involved in constructing end use scenarios in design. It is also necessary to connect this to the simulation. I combined the theoretical concept of a *design-centred view on simulation* with game design tools and methods and real-time functions.

Drawing on these elements, I propose the *Contextual Simulation Space Model* and the *Contextual Simulation Process Model* that refer to the use of game engines, modelling and simulation of systems, behaviours and tasks in real time to explore present events and future scenarios to conceptualise user-centred design. I have created a theoretical model map and a process model showing the relations between the tools, method and actors to explain the concept elements (see Fig. 35).

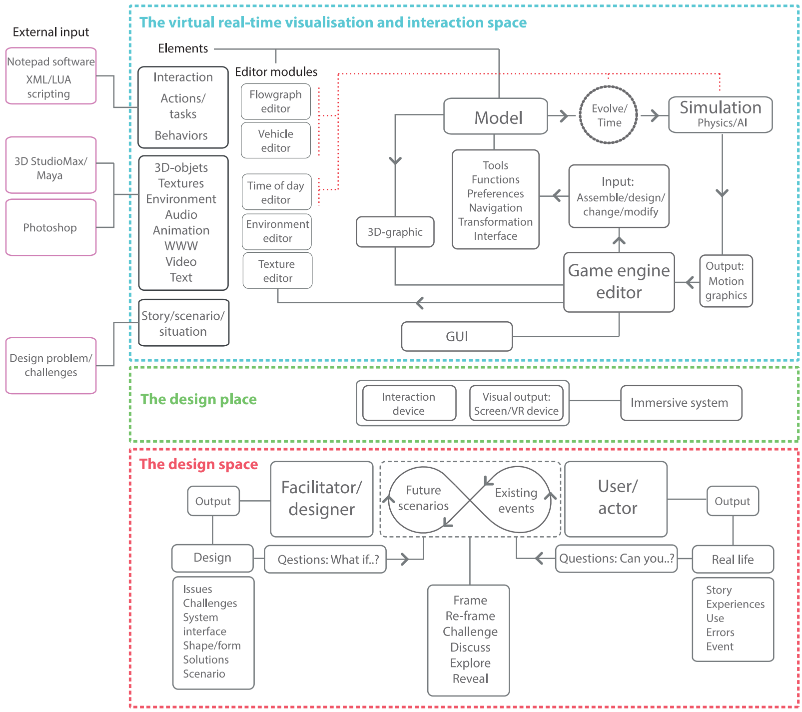

Figure 35. The *Contextual Simulation Space Model*.

This *Contextual Simulation Space Model* has been constructed as a mean to create shared understanding between the designer and actor or user based on a given design problem. The process entailed in the model allows present events and future scenarios to be mediated and shaped using the game engine as a mediation platform, where different media can be presented and simulated. The model is separated into three spaces: 1) *real-time visualisation and interaction space* that represents the virtual world inside the game engine, 2) the *design place* that represents the interaction and visual output devices that makes the physical immersive system, and 3) the *design space* that represent the present design situation between the designer, user or actor.

I will now relate the *Contextual Simulation Space Model* (Figure 35) and the *Contextual Simulation Process Model* on two theoretical perspectives. The first is a map of the elements and the relation between the three spaces of *the real-time visualisation and interaction space, design place* and *design space.* The second view describes the process of the contextual simulation process in a collaborative design setting.

The real-time visualisation and interaction space

As mentioned in Chapter 2, the game design process contains several similarities to how we approach UCD. Its' focus on designing for user experience and uses cross-disciplinary designer (Crawford, 1984; Salen & Zimmerman, 2004) to create stories or narratives for game play. However, the use of game development tools is not integrated as part of UCD processes. In this section I will describe and visualize how game engines and simulation function as tools for scenario creation and simulation.

The real-time visualisation and interaction space represents the space inside the game engine (Figure 36). The *game engine editor* with its *graphical user interface (GUI)* is the main interaction interface with the game engine software connected to interactive input devices (mouse, keyboard, 3D mouse and gamepad) and visual output devices such as screens, projectors or immersive systems. Through the game engine editor, events and scenarios are modelled using *editor modules* (e.g. Flowgraph editor, Time of day editor), *external input* (e.g. Lua and XML scripts, 3D assets) and the game engine boundary conditions, such as graphic properties, functions and transformations.

The *model* is designed based on design *elements* depending on what is needed. These are divided into three competence groups relating to game design process theory: programing, art and story design. In the contextual simulation process, the designer practices all these roles to varying degrees. When designing interaction, actions, tasks and behaviours that occur through programing and scripting, I propose that the readymade script can be re-used by changing some of the script variables. However, there is a problem in that the behaviour has no similarities to a pre-made script or code, and it thus might be necessary to enlist expert programmers to create unique code.

Assets such as 3D models are made using animation software like 3DStudioMax and Maya. Dummies, pivot points and proxies that are modified in the animation software are used to communicate with the LUA and XML scripts creating object behaviours. The object UV textures are flattened in the animation software, and textures are created in Adobe Photoshop. 3D Objects and textures are then exported to the game engine using a plug-in, and the scripts, objects and textures are assembled in the game engine real-time environment. The model also consists of a story, scenario or situation that is being created in the scene and visualised. The story is often based on the design brief and challenges related to it. This work is done through a discursive process between the designer, actor and user before the contextual simulation processes take place.

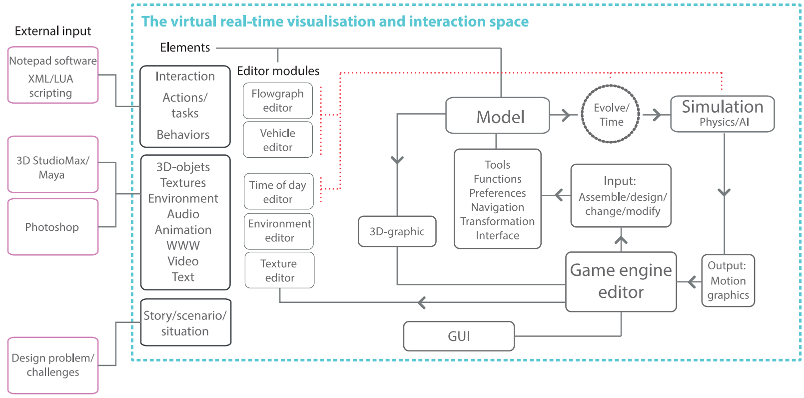

Figure 36. The real-time visualisation and interaction space. Pull out from the *Contextual Simulation Space Model*.

When the model is created and assembled, it can be simulated. The process of assembling the model in the game engine is a static simulation that shows the environment, 3D objects and textures. With the push of a button, the environment, physics and AI can be simulated in time, based on Flowgraph actions and object script programmed behaviour producing an output of motion graphics. This makes for a dynamic continuous simulation that can evolve through deterministic input according to, for example, object physical properties or stochastic, or more random, input data based on variations, such as human input. As a result, the game engine can simulate several systems simultaneously, where the simulation state changes according to modifications in real time. The game engine editor modules help in this process by making it less necessary to switch between third party software.

The design place

The collaborative design session between the designer, actor and user takes place through a physical environment of a *design place* with computer *interaction devices* and visual output, such as computer screens and VR devices (Figure 37). *Immersive systems* such as SimSam, designed for groups of participants, have been used in similar collaborative session in other fields. In some of my projects, I have used our immersive system SimSam, which I have found is better suited for in-group sessions with several participants. Furniture, light, air and temperature are also important elements. In SimSam, I have tried three different types of chairs and tables in the different collaborative sessions. I have found that relaxing chairs stimulate discussion, but not creation and interaction of boundary objects. Taller chairs and tables invite more movement and activity; however, they are not preferred for presentations lasting over 20 minutes. Sometimes, I have changed between different types of chairs during a single design session in order to optimise the work situation for the different process stages.

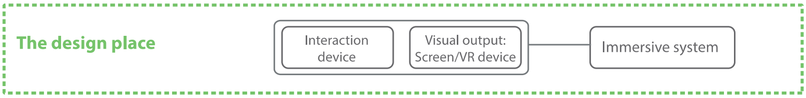

Figure 37. The design place. Pull out from the *Contextual Simulation Space Model*.

The design space

The design space is the process that happens between the designer or facilitator, and user and actor (Figure 38). The game engine works as tool and boundary object as a means to support and evolve the design space. The design place works as an interface between the game engine virtual real-time space and the design space in collaborative design sessions.

Between the designer and user/actor there exists constant movement that toggles the present and the future. The designer represents the evolution of future scenarios by changing existing situations into preferred ones. The user and actor represent the existing event that has occurred in situations. This is iterated in discussions through framing, re-framing, challenges and exploration, revealing the design factor and triggering new stories, events, experiences expressed by the user and actor. This drives the process towards questions about what is discovered in present events and via future scenarios. This design space is a real-time conversation in which questions, answers and iterations may even have a contentious evolution. The game engine also facilitates a real-time virtual environment thereby rendering the discursive process into pictures as static and dynamic simulations.

In the static simulation mode, the model is explored using the free perspective view enabling the designer to visualise parts of the elements discussed. An example of this is the dynamic positioning operator (DPO) discussing the radar system, which is visualised in the virtual environment as a static model enabling the user to use it as a reference to his real world experiences. The radar system is located on the real world ship which is different from the one used in the representation. The DPO then points out the differences between the systems. This situation would probably not occur if the radar system in the virtual world were the same as in the real world. An ill-structured simulation model can trigger discussion; however, it still needs to represent the basic system structures.

In the radar example explored with the DPO, this structure of the system structure LOD was (1) Context: polar area with icebergs; (2) Operation: drill rig supply; (3) Task: rig approach; (4) Equipment: supply ship; (5) Navigation: radar; (6) Radar angels; and (7) Radar position on ship.

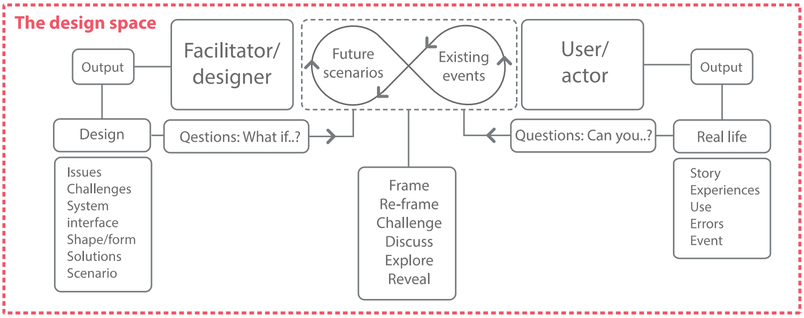

Figure 38. The Design Space. Pull out from the *Contextual Simulation Space Model*.

All these elements were represented in the discussion between us in detail. The DPO connected all these elements when shaping his argument. The use of a model inside the engine makes it possible to explain relations in systems, technology, context and functions; however, when the discussion goes in to a mode of sequences of tasks and events over time, a dynamic simulation method is required.

The Contextual Simulation Process Model

The *Contextual Simulation Process Model* (Figure 39) explains the iterative process when using the contextual simulation process in which design methods are used in combination with the game engine and simulation. I will explain the process by going through some typical steps in the process. The processes are slightly different for each project, but they typically start with a first meeting between the designer, actors and users; the actors present a project and the designer presents the contextual simulation process while showing earlier design work.

At this stage, it is critical to map the challenges and issues related to the project where (1) I am, trying to isolate elements related to context, operation, technology, interaction, manufacturing and marketing. It is important to include all these elements to understand the holistic picture. It is then possible to analyse individual problems and relate them to the overall system and get specific about what needs to be researched. Giga-maps are a helpful method in this process. (2) In the next step, we discuss how to approach the problem and what needs to be simulated and how. (3) After the meeting, I start modelling test visualisations and simulation based on elements needed and various data inputs such as 3D object, environment, textures and other media. I send the results in video form to the actor to discuss the different functions using data from the actor, existing models, or a web library. After agreeing on its functions, we start planning how it is to be used in a collaborative design session. In this phase, we are in an explicit design space, where existing concepts and data are used in the modelling. Thus, at this stage, we often know what directions the discussion might take. I therefore add functionality to the model so it can be modified in real time in collaboration with the actors and users. Depending on the number of actors involved, I select the immersive system for the design session. I also often involve several other design methods in these sessions such as storytelling, presentations, giga-maps, collaborative sketching and re-framing.

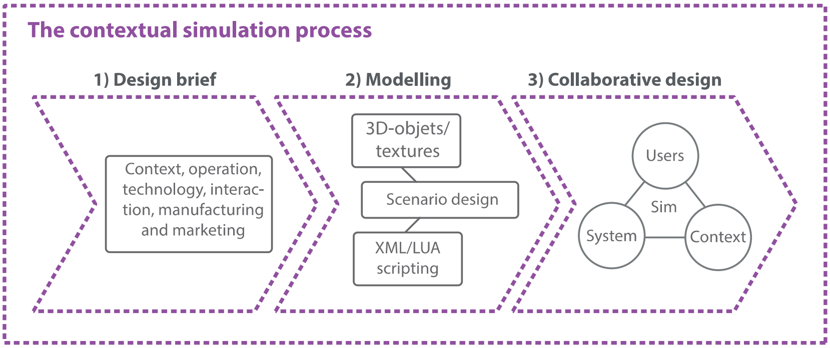

Figure 39. The *Contextual Simulation Process Model*.

When the game engine is used, I start the process by explaining the model and its functions and how it can be used. Then, I run the pre-made scenario simulations as an introduction to the discussion. When a topic is addressed, I run the simulation again focusing on that specific topic using the dynamic free movement camera. At this point in the process, the actors and users often start describing experiences or contextual relations that inflicted on the situation. We start building a network of relations that influence the design, and it is possible to converge or diverge the design space based on the users' and actors' inputs. Scenarios can be re-simulated using deterministic input or changed through real-time stochastic human-in-the-loop inputs.

An interesting aspect about this type of simulation is the continuous dynamic output that is mediated in real-time by the computer and reflected on by the participants in real time, where the model can be changed in real time. This real time loop is driven by the computer simulation and mediation, the participant's ability to reflect on the scenario evolution and the ability to interact and change it. In contrast to Schön's (1983) example of the reflective practitioner, in which examples are given using drawings as boundary objects in a design discursive process between two architects, the dynamic continues the simulation using game engines and provides a second part in this process that drives design.

Sometimes users argue about the direct design changes required, which is often a dilemma in design. However, it is better to think of this as the user expressing their needs rather than direct solutions. Nevertheless, it is important not to neglect the users' proposal when iterating the scenario. If it is possible to visualise and simulate the user proposal, this tends to provide an enthusiastic momentum to the discussion. This might be because it gives participants a feeling of being able to change the situation. At this stage in the process, we have moved toward an implicit stage, where both past events and future scenarios trigger indirect knowledge.

The contextual simulation process is also iterative, dynamic, reflexive, recursive and adaptive not just projecting a design process en route (Figure 40). There are activities continuously interacting with and influencing the design process in a more stochastic sense. This involves aspects such as users, actors, knowledge, technology, information, framing and re-framing problems, project trajectory, and activity levels on meetings and material production. Design process might therefore have several different design pathways that existing simultaneously and that may continuously diverge and converge in the same design space.

Summary

In this section, I have described two theoretical perspectives in mapping and describing the contextual simulation process based on the empirical research presented in *Chapter 2* and the simulation concepts presented at the beginning of this chapter. The models are for use as guidelines as how to apply simulation in practice and as a method to approach complex design issues such as those described in the maritime sector. The models should not be seen as rigid systems, but, rather, they ought be changed according to the needs of the design process.

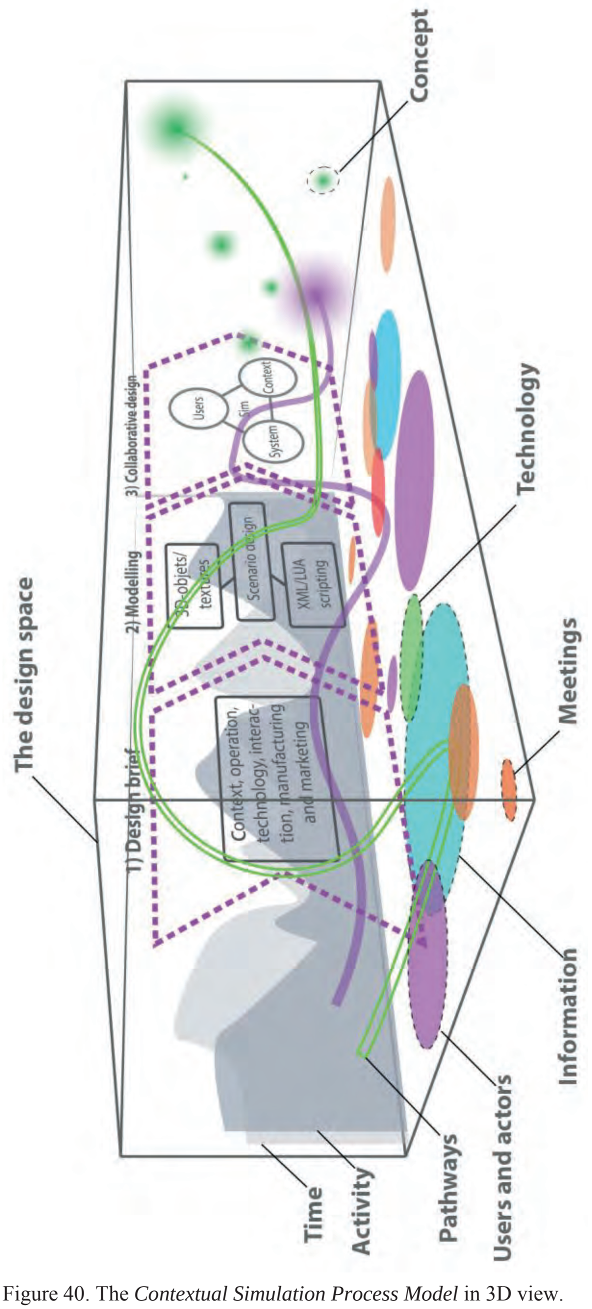

Figure 40. The *Contextual Simulation Process Model* in 3D view.

CONCLUSIONS

Since human error is the primary cause of maritime accidents (Rothblum, 2000; Bjørneseth et al., 2008; Michelle et al., 2002), it is generally acknowledged that there is a need for increased focus on users in complex operations in maritime design and innovation (Lurås, 2014; Lurås et al., 2015; Mills, 2006). However, implementing UCD for maritime design is challenging due to the complexity of the situation in which users collaborate, often operating in multifaceted work areas, changing weather conditions and advanced safety-critical activities (Hukkelås, 2013). These processes exist in a multidisciplinary design space where collaboration is needed to create a shared understanding between actors in order to develop new designs. In these types of settings, it is difficult to use traditional UCD processes to design and explore new ideas and concepts because access to the actual complex maritime context being designed for is often very limited (Lurås & Nordby, 2014). Methods and tools developed in human factors research (e.g. Flach, 1996) have been applied to critical work environments, however it is a challenge to use them in the process of conceptualisation in UCD because they are primarily not developed for FFE (Koen et al., 2002; Koen 2001) innovation.

In UCD scenarios (e.g., Buur & Larsen, 2010) are often used to approach systems, users and context in a holistic setting utilising methods such as: storytelling (Lerdahl, 2001), visual storytelling (Buxton 2007), exploratory design games (Brandt, 2006) and experience prototyping (Buchenau & Suri, 2000). However, it is a challenge to approach the complexity of maritime operations using these existing tools and methods because scenarios need to be explored through a time-based interaction, on micro and macro operational levels where behaviour of systems and users can interact with contextual boundary conditions (Hjelseth at el., 2015).

I have found that it is necessary to develop new tools and approaches that support maritime UCD in order to better understand the operations, how the systems and tasks relate to the context and how both relate to a culture of safety and risk thinking in design. To do so, I have investigated how designers design for users in safety-critical and demanding maritime operations and how we can apply simulated scenarios to aid the process.

To tackle these challenges, I posed the following core research question and four sub-questions that address how new simulation and scenario approaches can be developed to overcome the UCD challenges that arise in the front end of maritime innovation.

1. How can new approaches through simulation be developed to overcome the UCD challenges that arise in the front end of maritime innovation?

Several techniques have been developed to approach simulation that include the human element such as human factors related research. Simulations of human-machine interactions use techniques such as walk and talk troughs (Meister, 1986), analysis of human errors in operation of nuclear control rooms (Beare & Dorris, 1983), helicopter task analysis (Hess et al., 2002) and simulations of driver performance (Cacciabue et al., 2007). Such simulations often include real humans in the simulation loop (Narayanan & Kidambi, 2011). CSCW research also focuses on humans in simulations such as simulation of human workflow (Zhang et al, 2008). Simulation has also been researched in UCD and other user related design activities (Aldoy & Evans, 2011; Kuutti et al., 2001; Mikchevitch et al., 2005; Manninen, 2000; Tideman et al., 2008; Gabbard et al., 1999; Zoltán et al., 2007). However, these approaches have mainly focused on simulations as a way of testing product or user experiences that are often at late stages of design were many design decisions already have been taken. This also requires a process of validation and verification on simulation model and output (Winsberg 2010).

To answer the main research question, I applied an action research (Avison, 1997; Hollingsworth, 1997; Miller, 1994) and research-by-design (Morrison and Sevaldson, 2010) approach. Through three design process case studies, all using collaborative design within the maritime industry, I have explored and analysed how game engine driven simulation of scenarios can be used to connect and understand users, operation and context. Importantly, the case studies were all carried out with industry partners, and they were all related to real design problems and processes. The process helped generate knowledge about the design challenges that industry partners face first hand, it also provided valuable feedback on how my new proposed approach relates to real industrial design process needs.

New approaches can be developed to overcome the UCD challenges by understanding the relation between simulation and UCD challenges that we describe as a *design-centred view on simulation* that also take up the concepts of gamification (Deterding et al., 2011) and real time status (Crawford, 1984).

I propose that there is a need to approach maritime design challenges by examining and addressing ‘design in use time’ instead of ‘design before use time’ based on the concept of Pelle Ehn (2008). To do so, we may apply design scenario techniques to mediate complexity, such as context, operations and users, where time and interaction are critical. However, data (such as images, videos and text observations) from the field are alone insufficient for immersing actors in the design process in the ill-defined and complex problems they face in a maritime context. Moreover, access to real maritime context is limited and impractical in UCD processes. This is the way simulators have been applied in conceptual design of ship bridges (Kristiansen & Nordby, 2013). The challenge of using ship simulators for conceptual design is the ability to use it as an efficient design tool. Ship simulators are very complex and require expert knowledge when scenarios and content is to be changed.

I have found that computer simulation techniques can be used to model user actions and behaviours as well as how the system evolves through time in a scenario that can help immerse the design processes in 'use time'. Furthermore, I have found that tools to model, mediate and interact with such simulations must work as a platform incorporating multiple forms of media, such as 3D models, animations, pictures and sound that can be used to shape the user situation and contextual relations. I have explored multiple forms of media through a practice-based research inquiry, applying different design visualisation and simulation techniques to the design processes. Drawing from this work, I propose that a game engine is a purposeful simulation tool adept at supporting design processes because it offers game-specific functions that enable designers to design specifically for user experiences.

My research suggests that computer-mediated scenarios can support a process of reflection-in-action that encapsulates the processes needed to collaborate and participate in the evolution and iteration involved in transforming scenarios as boundary objects in real time. To better adapt a simulation to design processes, I introduced a *design-cantered view on simulation* that draws on research related to gamification and real-time interactions. A design-oriented view of simulation offers UCD a way of using simulation in a conceptual design practice that focuses on converging the design space through exploration and situates the design setting within the user context.

To elaborate on the main research question, I have further formulated four sub-questions to expand upon the relation between the design process, the simulation and the tools used for the simulation.

1a. How can simulation, as a tool and process, be explained in UCD?

In order to better understand the role that simulation plays in maritime design processes there is a need to develop a new theoretical concept that describes and situates simulation in relation to UCD. Using simulation in UCD in the field of maritime research is different from the way it is applied in social and natural science research mainly because of the differences in the knowledge production needs for those fields. The natural and social sciences predominantly focus on using simulations to experiment on and test phenomena, where the process of validation and verification is critical. Simulation techniques such as those drawn from natural and social science (e.g. Winsberg, 2010; Hartmann, 2005) are based on principles of technical rationality that mainly focus on 'how things are', in contrast to design epistemology that largely deals with 'how things ought to be' (Simon, 1969:4). This means that UCD needs to approach simulation differently than applying traditional simulations techniques from natural and social science. UCD deals with producing qualitative data, such as interaction experiences (Usability Professionals' Association, 2014), as well as exploring situations that are often connected to ill-defined (Lawson, 2006; Lawson & Dorst, 2009) wicked or unwieldy (Rittel et al., 1973) problems that cannot be solved by using rational analytical and numerical approaches. In most cases, the simulation techniques I have researched come from natural and social science, and they focus on numerical output; however, the area of application and design conceptualisation are mainly based on human experience and needs (Thomson, 2005). Therefore, I have developed simulation techniques that are built to explore and converge the problem space rather than apply reduction techniques that are often used in traditional technical rationality simulations.

Concerning the development of a *design-centred view on simulation*, the three scenario-oriented concepts of simulation, gamification and real-time interaction allow us to look beyond UCD as a component in complex product development processes towards becoming a facilitating platform that connects multidisciplinary collaboration in a hybrid and holistic design setting. The focus on scenario creation that is driven by users, tasks, operations and systems becomes central for all designers that are involved in designing because it is able to connect these four components and communicate the individual designer's scope.

I have also developed the *Contextual Simulation Space Model* to explain the realisation between UCD processes and simulation as tool. The model describes the simulation tool structure and functionality situated in a collaborative design space were scenarios are developed. By explaining simulation in relation to UCD I hope this research can lead to better understanding of how UCD and simulation are connected and can be developed further.

1b. How can gamification improve UCD processes?

Game technology, such as the type found in the tool game engines, is designed as a means to create gaming experiences. Gamification research (Deterding et al., 2011) focuses on the use of this technology and these tools and applies them to applications other than gaming. Game design itself is also focused on designing for user experiences (Sheller, 2008). The main challenge of using game technology in design is the skills and competence needed to apply such a tool in design practice. Thalen and Voort (2012) have interviewed 40 designers about the use of VR applications that are also based on game engines. They found that most designers could see the benefits in implementing such technology in UCD, but it was necessary for the designers to involve expert competence to facilitate the game engine and VR tools. However, game engines have now been developed with editor interfaces much like 3D CAD software and graphical interfaces controlling code. This makes learning and implementation of the technology by designers much less demanding.

In the research presented earlier in this thesis, game engines have been used to model scenarios simulate time-based design, human-in-the-loop integration and platform to share and to combine different types of media and real-time scenario interactions; they have also been used as boundary objects in collaborative design sessions.

I have found that game engines provide an efficient tool for designers to construct and visualise scenarios that can be used for UCD. Game engines provide a 3D virtual environment were context, objects, systems and users can be constructed (Wei, 2010). The different simulation techniques allow time, interactions and physical space to be integrated into these scenarios, making them a time-based design tool. The physical space simulation makes it possible to mimic object behaviour, e.g. buoyancy and contextual boundary conditions, such as gravity and wind (Nideffer, 2003). Simulations are also used to run the scenario evolution using trigger mechanisms that enable interactions within these scenarios. AI integrations can also be used to mimic human logic and behaviours.

Different types of player interaction integrations make it possible to use human-in-the-loop integrations in these scenario simulations. However, in my approach, in the early phases of the design process, it might be better to facilitate user involvement without retaining the interaction loop. Taking that approach would help prevent the designer from focusing on the game engine interaction implications of users controlling an avatar without practice.

I have found that game engines also provide a platform to share and combine different types of media that can be used to construct scenarios that include such elements as videos, sound, 3D models, animations, text data, html web pages and images. The game engines allow for real-time modelling as well as real-time interactions during simulation of the scenarios. During collaborative design sessions, the game engine and scenario become boundary objects for collaboration and user involvement. Because the game engine allows for real-time interaction and modelling, it becomes a shared tool for reflection-in-action.

We have explored and explained how gamification can influence the process of constructing simulated user scenarios in UCD processes. This can help designers to expand the use of gamification to use highly technical tools to create immersed user experiences accessible for UCD processes. This can place the designer in a better position when trying to understand existing situations and implications of future ones.

1c. How can the use simulation tools influence the understanding and manipulation of time in UCD processes?

Time is critical in any type of interaction process, especially in safety- and risk-critical operations where behaviour and consequences have implications for user situation awareness. Few design tools have time-based capabilities that can combine interaction with context of use, operation and user engagement (Selvaldson, 2004). Scenarios in UCD are often used to create this type of holistic setting, but the tools and methods often lack the ability to construct and mimic detailed time-based interactions. One of the most important components of a design tool is not only the ability to model time-based interactions but also to modify them as material for exploration, ideation and conceptualisation en route (Sanders & Stappers, 2008). I have found that game engines, and the simulation techniques they use, provide the capabilities of modelling time and real-time tool interactions that transform the simulation into an interactive design material. The real-time functionality of these game engines makes simulation a part of the reflection-in-action process because it allows for real-time interaction and construction of the scenarios. Thus, the use of simulation becomes more similar to a sketching technique that provides instant feedback loops. The process model places simulation and scenario development into a system that is driven by both the discursive process between the design actors and users and the scenarios that evolve through the simulation.

Through better understanding of how simulation and gamification influence time based methods it is possible to find new and better ways we can approach scenario development and interaction. Because the time element is critical when designing for users exposes safety and risk critical environments it is important to be able to manipulate time. This shows the importance of possible time based scenario simulation tools in UCD.

1d. How can we conceptualise a model that connects the relations between UCD, simulation, gamification and time?

Three concepts - my own *design-centred view on simulation* and existing concepts on gamification and real-time interaction – seem to me to be critical when using game engines to simulate scenarios for safety-critical and risk-critical operations in the maritime sector. The first concept is the *design-centred view on simulation* that positions simulation in relation to UCD, ill-defined and wicked problems, reflection-in-action and conceptualisation. Gamification provides efficient tools for modelling and facilitating scenarios and simulation as boundary objects in collaborative design sessions. The concept of real-time interaction provides a perspective on how to approach time-based interaction in scenarios as material in a design practice. However, this concept has several implications; interaction, complexity and ergonomic issues might prove to be difficult to construct in these scenarios. Due to some interaction being difficult to model, the scenario model might be ill-defined. I have found that it is critical to carry out a scenario trial before the collaborative design session so as to be aware of what is and is not possible to perform in the scenarios. However, in some cases, an ill-defined boundary object might trigger interesting questions about the factors that are missing from the object of enquiry (Star, 2010).

Based on these concepts, and on a design practice using the scenario and simulation approach, I have developed two models that explain how the tools, the physical location and the design process connect in different spaces. I have named first model the *Contextual Simulation Space Model* to explain the realisation between UCD processes and simulation as tool structures and layers on how scenarios are developed from a design space, materialised and simulated. The second model is named the *Contextual Simulation Process Model* and it exists in two versions. The first version describes in a structured way the different process steps in constructing simulated scenarios. The second version describe the process in a stochastic process that changes course according to unpredictable design process inputs. The different elements of scenario construction, simulation and real-time interaction are explained, as is how this connects through the physical place to the design space that exists between the collaborative actors during a collaborative design session. These models make it easier to understand the simulation structure and functions in simulated scenarios connects to UCD processes.

Through the research in which the simulation of user situations in game engines was applied using real-time interactions, I have identified an approach that can be used to design complex and critically-demanding operations. This type of scenario simulation becomes a boundary object in shaping and understanding existing situations, and it can be used to design future scenarios that can be further explored in order to identify information that can be used to inform the design process.

I have found that simulation can play a role in evolving the scenarios used in the design. It can keep track of the time element in these scenarios and it can mimic real-world conditions to construct a setting that reflects real-world situations. Several simulation techniques which are concerned with using simulation in a process of testing concepts or prototypes, often with simulators (e.g. Piovano et al., 2012; Craighead et al., 2007), or the design of VR interactions, have been applied to UCD (Thalen & Voort, 2012). My research addresses fundamental issues related to using simulation in virtual environments for UCD, and the research presented in this thesis has created this ground layer that is critical when applying computer simulation in UCD practice.

However, the approach to simulation as part of a design method needs to be different than the method that is traditionally used in techno-rational perspectives (e.g. Winsberg, 2010; Hartmann, 2005). From a UCD perspective, simulation can function as a boundary object that evolves through and with a discursive process. The goal of simulation might not be to design a specific product; rather, its goal could be to explore the factors that have implications for the design as part of a larger holistic setting. I have found that a simulation tool used in the design process requires the designer to focus on visualisation and plasticity when determining how to construct and explore the scenarios. In this regard, game engines provide the tools and media platform that create holistic game experiences by mimicking real-world interactions.

My method of using simulation in UCD could change the way we approach innovation in the maritime sector because it highlights the importance of this type of design. The approach introduces a more radical design strategy, one in which the emphasis shifts toward designing for and with the user; thus, it can position UCD in a more central role and raise it to a level that makes use and users central in developing innovation strategies. This makes it possible to address safety-critical and risk-critical operations in order to help decrease human failure as the main cause of accidents at sea.

It is possible that this approach might also have implications outside the maritime sector as well, since there are many safety critical design areas in addition to other non-safety critical design contexts that have different issues of complexity and time. It is important that design centred inquiry be extended and further investigate, understand and broaden the perspective on simulation in UCD.

FUTURE DIRECTIONS

Recent years have seen the introduction of several new types of interaction devices changing the way we interact with and through computers. The game industry has become the leading developer of visualisation technology finding new ways to mimic the real world in all of its dimensions. Through these new simulation techniques, it is likely that we will be able to increasingly mimic real-world behaviours. The world is also becoming more complex, requiring new approaches to solve problems, and designers will develop new tools to help them explore problems and needs. I think computer simulation is a powerful way of exploring and revealing complex relations between context, systems and users, and in some cases, it might be the only way to explore and understand multiple systems with individual behaviours interacting.

All this development is pushing towards a resurgence of virtual reality (Saggio & Ferrari, 2012). Current developments already make it more difficult to distinguish between vitality and 'reality'. It might be argued that even reality has become virtual, like military drones used in combat where the pilot executes firing on the enemy through a computer screen in an office building thousands of kilometres from the target. The resemblance here with computer games is striking. However, as the military is trying to move away from reality, computer games are moving towards reality.

In the past year, the Oculus Rift head-mounted immersive VR display, with six axis head tracking has been mass-produced, enabling developers to start making VR applications for the consumer market. The technology was invented in the 1990s, but it has not until now that the quality and price have been scaled to an affordable, affluent consumer, entertainment product. If the commercial Oculus Rift is released as planned in 2016, it might revolutionise how we perceive other dimensions of the simulated.

Already today, technology such as Leap Motion enables the possibility of augmenting the Oculus users' hands inside the virtual environment, enabling the possibility of more immersed interaction. WebGL is an Internet based virtual environment technology. In the Ocean Industry Concept Lab at AHO, we are now exploring the possibility of a distributed cloud simulation system through WebGL. This can have several layers of simulation data input and simulation nodes for specific simulation techniques. These data and simulation techniques can then be combined in a shared virtual environment for distribution through the Internet. The simulation calculation process can be effected via a powerful computer connected to a 'simulation cloud' and distributed through a virtual environment to laptops or mobile devices.

Consequently, for design I think it is important to understand the use of the virtual environment as a platform, tool and medium without being seduced by VR technology. In my view, some VR research on design processes have been carried out not because there is a clearly defined need for them, but because it is possible to do so. In this thesis, I have attempted to create a foundational layer that links design needs with the game engine and simulation as a technique and tools to solve design challenges that would be impossible with other approaches. An example of this is simulating eight ferries in operation while changing their direction and speed, and viewing the co-created scenarios at any angle in real time. Bringing VR into this type of design approach is the next step in the research. I have found that by using the Oculus Rift, the affective character of immersion creates emotional reactions that cannot be obtained through a computer screen. The sense of immersion tricks the mind into a state of feeling presence in another dimension, giving the virtual a tangible materiality. This can only be described as the difference between looking at a picture of a room and being in one. Combining such immersive tools with simulation itself rich in photorealistic visualisation, will most likely continue to present opportunities and challenges for the design-situated shaping of future experiences in not only leisure but also work settings such as those of the maritime sector.

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Part 2

Publication 1

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3D-VISUALIZATIONS AS A MEANS FOR ENGAGING USERS AND ACTORS AS CO-DESIGNERS IN THE FUZZY FRONT-END OF PRODUCT DEVELOPMENT

Snorre Hjelseth,
The Oslo School of Architecture and Design, Vestfold University College, Norway.
snorre.hjelseth@hive.no

ABSTRACT

This paper explores the role of photorealistic images created by computer generated 3D models when designing complex systems in the fuzzy front-end of innovation. It discusses how realistic visualizations can engage users and actors as co-designers in early stages of product development. The paper introduces the SimSam project as a case where participation from expert-users and stakeholders has been critical for the decisions made in the design process and the ability to implement the selected design. The computer generated visualizations were a key element in engaging these participants in the front-end of the process. This paper takes up this position with reference to computer generated 3D representations and their potential in helping realize complex relations between tools, participants and representations in product development. The results show that the 3D-visualizations had an impact on involving participants in the design tasks and when implementing the concept on internal and external levels.

Keywords: Photorealistic representations, co-design, product development.

INTRODUCTION

This paper reports results of an exploratory case study where photorealistic 3D computer generated images were used as a means for engaging users and actors as participants in a co-design project in the Fuzzy Front End (FFE) of product development (PD). Below I describe how the participants were able to contribute to the design process and how this result affected the implementation of the design itself. The central question the paper poses is: How can photorealistic images created with computer generated 3D models be used as a means to engage users and actors as co-designers in the front end of PD?

The paper refers to a case called SimSam that covers a design process where a new type of innovation and simulation-lab was designed. SimSam was devised to explore and to develop possible new solutions for maritime innovation processes. In order to develop SimSam, a multidisciplinary team of designers, engineers and users was established. Photorealistic images of the possible designs and product scenarios were produced using computer generated 3D models in order to facilitate communication and collaboration between the participants.

DESIGN IMPACT IN THE FRONT END OF INNOVATION

Innovation might be seen as a combination of two factors. One is the invention part, where previous ideas are combined into new ones. The second part is the ability of implementing ideas into the world and is usually seen as the economical part of the innovation process. The innovation processes in PD might be seen as having three phases: the fuzzy front end, new product development and the commercialization phase (Koen, 2004). It is in the FFE of innovation it is most likely to create breakthrough products from both of the perspectives of invention and implementation. A breakthrough product might be defined as a product that is new to the world and that is several cycles further in development than the output of an incremental process. In the FFE it is possible to respond to costumers needs, wants and desires with most impact (Cagan and Vogel, 2001). A company environment allowing employees to be open and speak their mind and be trusted are important factors to stimulate breakthrough discoveries in the FFE (Koen, 2004).

The design space in the front end of innovation is complex. Often problems are ill-defined or wicked and have a number of unknown factors. The designers` way of dealing with this type of problem is described as solution driven design (Lawson, 2005; Lawson and Dorst, 2009). Through creation of solutions to ill-defined problems it is possible to reflect back on the factors that define the problems.

DESIGN AS A COLLECTIVE PROCESS

Often when working with breakthrough solutions in the FFE, the process itself becomes complex. Some of this complexity deals with the need to integrate multidisciplinary knowledge in a design process. Tim Brown explains it like this: “a competent designer can always improve on last years new widget, but an interdisciplinary team of skilled design thinkers is in a possession to tackle more complex problems”. (Brown, 2009: 7)

In design research the collective and collaborative process in a multidisciplinary team is referred to as Co-design: “Co-design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed”. (Kleinsmann, 2006: 30)

When design becomes multidisciplinary the collaboration and communication within the development team becomes intricate, and a critical part of the process is to obtain a shared understanding between design participants (Bucciarelli, 1994). The knowledge between participants is shared orally with the support of representations like drawing and models (Kleinsmann and Valkenburg, 2008).

In contrast to the user-centered design tradition, co-design is about integrating all members that has a stake in the product to be involved in the design process. This means that users are not only observed, but are active participants in solving design problems. A user who is involved in the design task might be seen as an expert on his or her area of expertise. This expertise becomes an important part of knowledge development, idea generation and concept development. In such co-design contexts the designer gets the role of a facilitator that generates tools for ideation and expression (Sanders and Stappers, 2008). This process might also be referred to as collective creativity (Sanders and Rim, 2001). To create shared understanding in a co-design process involving users is more complex than within a group of experienced developers. In contrast to designers, users have little experience in development processes where representations play a critical role. Representations created in the FFE are often abstract and are materialized through sketches, drawings, mock-ups or physical models. If the co-design process is going to become successful it is critical that the user understands these representations.

Representations are used in product design processes in order to share ideas and thoughts. In the user centered design tradition the user is often studied as an object and not engaged in the design process itself. Participatory design, co-design, co-creations and user driven innovation are areas in design research that explore such collaboration.

REPRESENTATION TYPES

Different types of representations used in PD have different qualities. These representations can be 2D drawings and 3D models, both physical and virtual. Representations have common factors that influence the way they are perceived, that can be described as criteria for assessment of visual representations. Table 1 shows the criteria proposed by different authors (Bates-Brkljac, 2010).

Such criteria are scalable. For example, a sketch can be very accurate or be imprecise. The criteria can also be mixed. Another example; a rendering might look very realistic, but might lack accuracy in dimensions. Visual representations might be categorized in many different ways. Categorizations might be grouped in professions, medium or subject (Buxton, 2007). Buxton describes five types of renderings: Sketch, memory drawing, presentation drawing, technical drawing and description drawing. These rendering types can also refer to physical and virtual 3D models.

3D software is usually not designed for design tasks in the creative ideation phases. Representations may have the characteristics of finished products, which might limit the design space for new creative solutions (Parsons, 2009). Detailed representations might be perceived as prototypes and draw attention to details that disturb the creative process and possible opportunities (Buxton, 2007).

The levels of accuracy and realism of representations created in the front-end might become a paradox in a collective design setting. If the representations are abstract, participants might lack the skills to read the representations (Powell, 1994). On the other hand, if the representations have a high level of accuracy and realism it might limit the creative design space.

VISUAL SIMULATION

Creating realistic images to represent ideas in a design process can be described as a visual simulation. Al-Kodmany (1999) has conducted research into the effects of using photorealistic representations created by computer photo-manipulations to engage public participation in urban planning. The results from this study show that the photorealistic “visualizations created through digital technology provided a common language for all participants”, this resulted in a rise of excitement from the users and a design that “reflected the community’s wishes and input and respected their cultural heritage”. (Al-Kodmany, 1999: 45) In a similar way, the research conducted in the SimSam case investigates how the use of photorealistic visualizations engages users and actors as active participants in a design process.

RESEARCH METHODS

During the design process of SimSam the author had the role of both a researcher and a designer. This way of actively involving the researcher in the activity that is being researched is referred to as participatory action research (PAR) (Hult and Lennung, 1980; Denzin and Lincoln, 2000).

The empirical data is produced through case studies in real-life situations (Yin, 2009). The participants in the case study were interviewed using a qualitative interview method (Kvale and Rygge, 2009). The interviews focused on the roles of the different actors in the design process, the collective design process and the use of representations. The interviews were recorded using a video camera and transcribed. The examples from the transcriptions have been translated from Norwegian to English by the author. Four actors were interviewed. The actors had the roles of a user, a designer, a project leader and an external stakeholder. They all were actively involved in the design process, where the external stakeholder had the role of a possible investor.

The research is based on an exploratory case study. This approach was necessary in order to explore different research angles when researching the subject, and at the same time work as a designer with the goal of making the SimSam-lab a success.

The criteria for the assessment of visual representations proposed by different authors

Appleyard	Sheppard	Pietsch	Radford
Realism	Accuracy	Abstraction	Abstraction
Accuracy	Representativeness	Accuracy	Accuracy
Comprehensibility	Visual clarity	Realism	Realism
Evaluability	Interest		
Engagement	Legitimacy		

Table 1. The criteria for assessment for visual representations proposed by different authors. Author reference, (Appleyard, 1977; Sheppard, 1989; Radford, 1997; Pietsch, 2000; Sheppard, 2001).

Figure 1. T_Visionarium in iCinema by Dennis Del Favero, Jeffrey Shaw, Neil Brown, Peter Weibel, Matt McGinity 2008. Video link: http://vimeo.com/28322411

THE CASE

BACKGROUND

The SimSam project started out as ideas about a future innovation facility. The concept was generated in parallel with Vestfold University College`s (HiVe) development of a new research and innovation center named FIN. This new R&I center was to house a new ship simulator as part of the new research and simulator development strategy in the maritime sector. A ship simulator is basically a large multi-projected cylindrical curved screen that displays the output of a virtual 3D-environment that is interacting with physical hardware consoles, which are standardized on ships. In the early summer of 2009 SimSam was suggested as an idea where the new ship simulator could be combined with design methods and thinking. This new idea about an innovation-lab was named SimSam and stands for simulation and collaboration (in Norwegian).

Inspirations for the idea came from The Oslo School of Architecture and Design, which had formed a similar concept named C-Lab. The ideas behind this lab were based on the use of design methods and thinking in combination with state-of-the-art visualization and modeling technology.

DESIGN METHODS AND TECHNOLOGY

In accordance with Capjon (2004) the design methods and thinking used in SimSam builds upon the use of representations as stimuli for expression and collaboration in PD processes. In order to reflect on and communicate ideas co-actors need to embody representational experiences through perceptual stimulation of the human senses. This involves that internal ideas must be externalized through a medium. Most often externalizations are combined in order to explain ideas meaningfully. The media in which the representations are created are critical and need to be adjusted according to the information being communicated. A representation that involves too little or too much complexity might change the understanding of an idea completely. Such representations might range from verbal communications to sketches and functional prototypes. If such representations can be easily modified on-the-fly, it is possible to obtain a dynamic creative interaction between participants. Industrial designers have special skills and knowledge in creating such types of representations.

Creativity can be understood as combining previous ideas into new ones. When such processes are taking place it can be a beneficial to make representations of these ideas and to make them available for all the participants (Figure 1). By being able to visualize multiple ideas and concepts simultaneously, they can form a platform for comparing and combining concepts into completely new ideas.

The concept of solution-driven design processes is one of the core principles built into SimSam –

through offering tools that enable users to create fast models and reflect back on problems in the design space. Much of the information implemented into PD consists in a digital format. The screens and computers that are commonly used allow only a limited amount of resolution on a limited space. The limited resolution allows you to display a limited amount of information. This is because most digital information and media are designed for computers used by individuals on single screens. If one uses a larger screen like a projector the resolution is often limited to 1080p HD.

By combining multiple projectors it is possible to create a large screen with a higher resolution. This enables the possibility of visualizing large amounts of information and media simultaneously. Figure 1 shows the iCinema project from the University of New South Wales in Sydney. The iCinema has the capability of playing hundreds of videos simultaneously on the same screen.

The interaction with the multi projection screen is a critical element involving user participation in SimSam. A traditional solution to such interaction is through a mouse and keyboard interface. The problem with the traditional interface is that it is restricted to single-user interaction. The SimSam philosophy involves that all participants in an appropriate PD process should be able to use and interact with the representations. A user interface that is more open for multiple user interaction might increase the level of user participation and might help the setting to feel less static and over-controlled by a facilitator. A touch-sensible tabletop was a solution we found for this problem. If we used a 50-inch screen we found that it enables multiple users to share the space around the interface with multiple interaction inputs. One capability of this type of interface is that it allows digital representations to be at the same level of accessibility for the whole development team.
Up to this point the SimSam was only an invention of how to combine new technologies in new ways. The context in which it should be used was unclear and there had been no decision about taking the idea further. To take the idea to the next level in the development process we needed to se how it could be implemented in real life scenarios.

FACILITATING A COLLECTIVE DEVELOPMENT PROCESS

If the SimSam was going to be implemented it needed to share facilities with a ship simulator. To implement the idea we needed to see if it was possible to combine the SimSam idea with some existing and future activities at HiVe. To do this we involved colleagues from different maritime departments to join the process and see if there were any possible scenarios to be implement into the SimSam concept. To communicate these ideas about how to use this technology for PD we needed some representations that explained the concept with more fidelity than an abstract sketch – because involved actors had to be able to understand what the technology looked like and the dimensions of the facility itself.

Using a traditional representation tool in this phase like hand sketches, physical scale models or mock-ups was problematic. The complexity of the technology and the dimensions of the SimSam challenged the representation principle. One of the representations needed to capture the overview of the technology put together in a room, and some of the representations needed to be on more detailed level of interaction between participants using the

Figure 2. This picture shows the SimSam-lab idea before the scenarios was developed and how the different technologies might be put together. By using the layered structure of the 3D models it was possible to make rapid changes to the visualizations.

technology (Figure 2). We also needed representations that were possible to change rapidly in order to visualize different scenarios.

We tried to involve actors from the maritime field. These actors had little experience in PD and using abstract sketches or drawings. The goal was to get a discussion going about the implementation of maritime applications, but we were not able to obtain a shared understanding of the SimSam idea. By creating a virtual 3D-model of the SimSam idea we were able to get a more detailed view over the technology assembled. We also placed models of people (personas) in the room to get a feeling of the dimensions and to create scenarios of interaction. After constructing the 3D-models in Catia and assembled them in Maya, we textured the models and rendered images from different camera views. The pictures were presented to the SimSam development team through printouts and monitors.

After presenting images of the 3D-model to the SimSam development actors, they became more enthusiastic about the idea. It was easier to get a shared understanding of the different technologies and how we were thinking about using it. After some discussion we started to form some interesting scenarios of how the SimSam-lab might be used. We created one oil-spill scenario where the lab can be used to simulate an oil-spill (Figure 3). The visualized scenarios show how multi projection screens and the tabletop can be utilized. The multi projection screen were able to show large amounts of data simultaneously that are critical for the operation and the tabletop made it possible for the actors to interact and simulate boats trying to collect and clean up the oil. The oil-spill scenario was engaging because of two recent oil-spills near the Norwegian coastline. The handlings of the cleaning operations have been heavily criticized because of deficient organizing skills.

Another visualized scenario was a ship design process of environment friendly ships (Figure 4). With this scenario we wanted to visualize how the SimSam lab is able to handle large amounts of information and how different design concepts can be compared and become part of a multidisciplinary collaboration.

One important aspect of this way of facilitating the design process was to combine the use of ship simulation technology to test and review the different designs.

IMPLEMENTING THE DESIGN

From ideas about design thinking and methods in combination with state-of-the-art technology the SimSam-lab evolved into concepts involving context and action scenarios. These scenarios were presented to the HiVe board, which in response decided to implement the concept as part of the new FIN R&I center. They decided to expand the project and introduced the project to the MarKIS network.

The MarKIS network is a maritime network combining commercial companies, universities and institutions from Denmark, Norway and Sweden. The purpose of the network is to establish a maritime collaboration network across Scandinavia. The SimSam concept was introduced to the MarKIS as a possible new way of working with maritime development. HiVe and MarKIS made a decision to collaborate with the development of SimSam and funded the project with 1.3 million euros.

Figure 3, The picture show an oil-Spill scenario simulation where information is placed on the multi-projection wall and a tabletop is used to combine physical representation with digital representations.

Figure 4. Pictures of eco ship design scenario.

RESULTS

The results from the conducted research where analyzed and it shows that the 3D visualizations had an impact on three different levels in the FFE of the SimSam development process. The different levels can be described as *internal* (the SimSam development team), *company level* and on an *external level* with external companies and organizations.

LEVEL ONE: THE DESIGN TEAM

Level one is the use of 3D visualizations to support communication and collaboration within the multidisciplinary development team. The issue regarding visualizations and realism in the FFE is that hi-fidelity in realism might have a negative impact on the creativity space. Based on PAR observations and the analyzed interviews, it was found that the 3D computer generated representations with a high level of realism impacted on the design process and the implementation process of the design concept. The results show that the design team actors were able to create a shared understanding using the 3D representations and involve users as contributors to the design.

When the designer was interviewed and asked how the different representations were understood, he answered: “External partners and users were not able to understand the 2D sketches, but this changed when we started using the 3D visualizations”. The designer also described that there was a change in enthusiasm on the part of the users when we started using the photorealistic 3D representations: “They were open to the concept, but their enthusiasm was limited because they did not see the possibilities in the maritime sector, but when we started to discuss the simulator using the 3D visualizations their understanding of the concept started to grow. They started then to see new possibilities using the concept within their maritime field”. This statement was later confirmed in the interview with the user.

When the project proceeded from the FFE to the new PD phase, new modifications were made to the design. These changes were represented with a 2D plan drawing and not as the earlier photorealistic images. The user representative stated through the interview that he had problems relating to the plan drawing and he had problems relating his knowledge to the new design.

Going from abstract visualizations to realistic representations and back again to abstract visualizations leaves some evidence on how the users were able to interact and participate during the design process. The enthusiasm the user experienced from interacting with the realistic visualizations might be due to the seductive visual qualities and the ability to realize their own thoughts and ideas simulated through realistic visualizations. At the same time, the participants were able to reach a shared understanding of the SimSam ideas, and to create scenarios of possible maritime applications together, based on real-life experiences. The development of these scenarios would not have been possible without the involvement of users from the maritime sector.

LEVEL TWO: THE COMPANY LEVEL

After the scenarios were completed they were used to create a shared understanding of the SimSam concept at the HiVe board meeting.

The project leader was asked through the interview if the photorealistic representations had any influence on the decisions made in the school board about SimSam. The project leader argued: “To use the pictured scenarios was critical for the decisions and has made it easier than understanding it through text, spheres and boxes".

As in any design process these gates of concept evaluation are critical. The evaluation of new concepts at this stage is often problematic because of lack in or proof of data. The project leader expressed that the board was not used to having concepts presented at this early stage with representations that had such a hi-level of fidelity. This made a change in comparison with text, spheres and boxes that can be described as more abstract representation being represented as symbol of things. Using abstract representations as the project leader explains might not reveal this diversity between participants at the decision-making stage. Representations that are pinpointed directly to realistic scenarios with realistic images might help to create a more unified and shared understanding that again can make decision-making easier and more precise.

The illustrated scenarios, created together with the users, made it easier for the board to understand the concept. Because the project had been able to involve expert users so early in the process it gave more reliable data for the board to evaluate.

LEVEL THREE: EXTERNAL COMPANIES AND ORGANIZATIONS

The research results show that partners that were attached to the MarKIS network were able to use the visualizations of SimSam to relate their own practice and areas of interest as possible new SimSam scenarios. When the MarKis network leader was interviewed she stated: "By using the SimSam concept we found possible new ways of changing the existing process of this type of development".

One of the problems she described as part of this type of maritime network is to manage the logistics between partners and interests that can evolve in to new innovation projects. Presenting realistic representations of possible innovation scenarios gave the MarKIS network new frameworks for how to solve these problems.

A critical factor of the MarKIS investment in the project was not only that the SimSam project represented a solution to their maritime innovation network, but also that the realistic representations made it possible to apply their own real-life scenarios into the SimSam concept.

These extracts from the interviews show that through using the photorealistic representations the participation was extended into other research and development networks, where it got applied to new fields. New scenarios created by the external partners have now become central design projects that are being tested in the SimSam-lab.

DISCUSSION AND CONCLUSION

This project has moved forward on two levels simultaneously; (i) through developing the notion of a theoretical framework when working in a multidisciplinary team of both experienced and less experienced participants and (ii) to actually implement these frameworks in the design being developed. The result of the study show how 3D visualizations can be used at different organizational levels to both develop and implement ideas created in the FFE of PD.

There is, however, a paradox concerning the use of hi-fidelity 3D representations in the FFE of a collective design process. The realistic imagery might give the participants an illusion that the design is finished – which will limit the creativity of the design space. On the other hand; using representations that are abstract may result in the participants' lack of understanding the representations. A possible solution for this problem is probably not an optimization of the different factors, but a flexible representation medium.

The layered structure of the 3D model enabled the designers to use the same representation in different stages of the development process. In one stage the representation was used to describe the SimSam idea and technology. On another stage the same representation was used to develop scenarios together with the participants. The developed scenarios were then used to implement the project on a company level and on a level with external companies and organizations. But could we have achieved the same results using only abstract drawings or physical models, which is a more traditional approach at this stage of the process?

The results show that there was little attention drawn to the project from colleagues when the first abstract sketches of the SimSam idea were made. Some of the participants did not remember that we used the sketches at all. The interviews show that a possible reason for the low initial attention was the low fidelity of abstract drawings and that participants had problems reading them and at the same time relating the drawing to the proposed technology. When creating the scenarios the visual representations needed to be from a bird`s view - capturing all the activity on the lab screens and at the same time being able to zoom in on specific interactions between personas. We also needed to be able to shift between different scenario settings. Fitting these specifications in a physical scale model was not possible (we actually tried this by building a 1:15 scale model using rapid prototyping).

Overall, the case study shows that employment of photorealistic images created by computer generated 3D models can have a useful impact on engaging users and actors as co-designers in the fuzzy front end of product development.

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Publication 2

Chapter 6

Innovative Conceptualisation Through Sense Stimulation in Co-lab Development

J. Capjon and S. Hjelseth

6.1 Introduction

Should collaborative lab developments be based on technological or human preconditions? This paper initially suggests how complex human conceptualisation patterns can be described and modelled comprehensively in an innovation framing. A research-based metaphorical model, called the Plant of Collaborative Conceptualisation (PoCC), is summarily developed and visualised. The model is then used as a template for the following process development including evaluation and choice of new ICT tools that can stimulate basic human ideation patterns. The resulting *SimSam lab* is based on a 360 degree maritime simulator adapted to negotiating and elaborating several alternative propositions, and simultaneously displaying all relevant background data. Resulting 'perception map' formats secure easy comparability and integration of parts into new solutions. And 'participative drawing' and 'display organisation' are achieved through employment of multi-touch technology. The paper basically describes the principles and reflective design process behind its realisation.

6.2 New Contexts for Co-innovation

This project originally addressed cross-professional collaboration challenges in the Norwegian maritime sector and how industrial design thinking can influence this basically conservative environment towards enhancement of innovation level. Development processes for ships, bridges, machines and multiple crew are highly complex, involving several knowledge regimes. The R&D team had special competences which early brought the process out of the maritime sector as such and into a landscape of human capabilities. When generalised preconditions for all human actors were matched with knowledge and technology from the maritime and ICT sectors, new opportunities emerged.

How can human preconditions for collaborative conceptualisation be described - and how can updated tools be adapted to support basic human conceptualisation patterns? Innovation can be understood as idea generation, development of the idea into a product or service and marketing of the result. The definition suggests that ideation is an essential aspect in innovation. New conceptual ideas can be created individually by one or collectively by many actors. In collaborative ideation and development processes the actors are supposed to be different, which can involve differences in education, personality, values, priorities, action patterns and languages - or in short; dislike mentalities. Innovative interaction involves breaking mental barriers and seeing problems from new angles, and diverging approaches, backgrounds and views are accordingly highly needed. But for many reasons integrating human differences in shared scenarios invariably have a tendency to lead into problematic processes.

Many collaborative innovation and learning labs have been developed that are basing their process approaches on new technology support (www.lilan.org/; www.elearningeuropa.info/; www.creativelearningsystems.com/). The developments have, mainly through behaviour studies, reported numeral success stories. Behaviour studies or related design studies do not, to the knowledge of the authors, model the human preconditions for individual or collective creative processes understandably to an audience of design/innovation oriented professionals. This, of course, has to do with the complexities and professional controversies of studies involving human consciousness.

In Capjon (2004), which is reported and slightly revised to updated premises below, two main objectives were: (i) to describe individual and collective creative processes seen from perspectives of dislike human actors and (ii) to develop an easily understandable model of a cross-professional innovation process, which includes diverging mentalities of participating actors. Some human preconditions for interaction will be summarised as basis for the following model - through cognitive psychology, neurobiology and phenomenology triangulation.

6.3 Sense-stimulation of Central Human Capabilities

In design oriented fields there is general agreement that shared conceptual *representations* will support communication between innovation actors. Some examples are: Ehn (1989); *hands-on-experience*, Star (1991); *boundary objects,* Perry and Sanderson (1998); *procedural artefacts,* Brandt (2001); *things-to-think-with*, Boujut and Laureillard (2002); *intermediary objects,* Bucciarelli (2002); *linguistic artefacts*. The representations are supposed to represent mental ideas materially and thereby basically stimulate body-based senses. They can be drawings/graphs on paper, calculations, mock-ups, abstracted or detailed physical models or the like. But ‘conceptual representations’ will also in the following include ‘virtual’ visualisation on computer screens or projected onto display walls.

Cognitive psychology has outlined mental processing in conceptualisation as being based on *internal visual images*. Finke, Ward and Smith (1992) describe how much of everyday thinking is based on formation and transformation of visual images and how pathways of creative exploration are often opportunistic and unforeseeable. Kosslyn (1995) has specified four types of processing of mental imagery; *image generation*, *image inspection*, *image transformation* and *information retrieval* from long-term memory.

There are basic controversies, *e.g.* between neurobiology and philosophy, as to the nature of human consciousness and so-called Cartesian dualism. Velmans (2000) presents an outline of consciousness where updated proceedings of neurobiology are embraced if they are not misinterpreted as its ontology; "no discovery that reduces consciousness to brain has yet been made". Consciousness, in his view, is restricted to situations where awareness or phenomenal content is present, and he specifies its three possible foci: space, body and 'inside'. Engaged human experience then is where *conscious awareness* is focused at will, and not in the brain where its physical representation is. But these 'locations' are seen as *two fundamental aspects* of being in the world. They can together account for individual perception - which belongs to the encompassing world totality where all individual views are embedded. This *reflexive monism* framework reconciles phenomenology and neurobiology as two valid and inter-dependable approaches to human action - and is seen as highly relevant for development of design oriented theory.

Lakoff and Johnson (1999) describe the neurobiological view of embodiment of experiences through synaptic brain cell connections. But in creative conceptualisation *breaking down old* embodied patterns through *forming new* embodiments of new solutions' advantages, become central objectives. Merleau-Ponty (1962; 2002) with his *intermonde* concept (between-world) describes a state of being between subject and object where wholeness can be immediately experienced. Ornstein (1986) describes between-world scenarios of *deautomatisation*, where movement, dance, play, rituals, music, aesthetics, contemplation *etc.* can break habits to achieve intuitive opening of the mind. Böhme (2002) likewise describes how *atmospheres* have high importance for communication through the connection they produce between actors, and how immediate perception of atmosphere and wholeness comes before separation of *I-pole* and *thing-pole*. Husserl (1900) basically describes how engaged experiences must converge repeatedly over time to achieve stable understanding or meaning. All these aspects contribute to the resulting description of a humanly foundation for a conceptualisation model.

6.3.1 Developing a Conceptualisation Model

Conscious attention can be focused at will between 'internal' and 'external' perspectives. Much used terms for these dialectic 'positions' are mind/world, subject/object, mentality/materiality, I-pole/thing-pole or spirit/matter. In a human ideation/conceptualisation process the consciously focused attention will be alternated between the poles, where each position is seen as a representation of the other. In innovative action a material model can be made to represent the internal perspective (idea) and a mental model, in turn, can represent sense-stimuli from the external model. A generated idea can be seen as a mental model resulting from dynamic interaction between internal and external foci. In emotional experiences the attention can be focused on wholeness instead of polarities.

Figure 6.1 depicts an (individual) ideation or conceptualisation process, where conscious attention (dotted spiral) originates in a between-world experience and gradually converges towards a matured relationship between internal and external representations through dynamic and interactive cycling between the two.

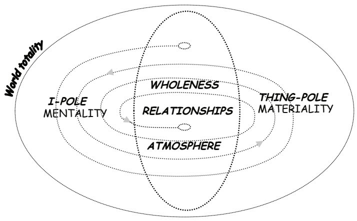

Figure 6.1. A basic conceptualisation pattern describing conscious awareness flow towards understanding

Figure 6.2 on the right side models the Process of Experiential Learning (Kolb, 1984), which alternates between the mental foci Concrete experience, Reflective observation, Abstract conceptualisation and Active experimentation, of which 1’ and 4’ are external and 2’ and 3’ are internal. On the left side is attached a model of a ‘design cycle’ agreed upon by four students (unfamiliar with Kolb or philosophy) reflecting on their own design work - which includes a material representation of their conceptual idea. Since Kolb focuses cognition (intellect) and the students focus aesthetics (emotion), the dislike aspects are seen as interdependent modes of design conceptualisation (called adaptive and formative respectively) - and connected through the material representation, representing both modes.

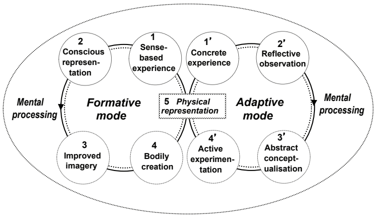

Figure 6.2. A cyclic design process showing interconnection between awareness on forming or adaptation aspects

Figure 6.3 expands the Figure 6.2 pattern by integrating the Figure 6.1 dynamics. Conceptual learning achieved through iterative mentality/materiality cycling converges towards an understanding (meaning) represented in the visual/physical model. The conceptual representation (model) in this scheme is supposed to represent (absorb) the actor's mentality - *e.g.* a vision of a conceptual solution.

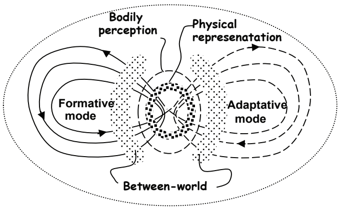

Figure 6.3. Model of an individual design conceptualisation process

Figure 6.4 further expands focus from an individual conceptualisation process to *a collaborative process* where several actors (3 in figure, but many more possible) cooperate towards shared understanding or meaning. Dislike individual formative and adaptive capabilities give differently depicted patterns for each actor. Here the fact that the (physical) conceptual representation can be shared (whereas the mental representations are private) produces *a unique opportunity for negotiations* between diverging minds - if it is produced in such a way that it basically can represent all the individual mentalities.

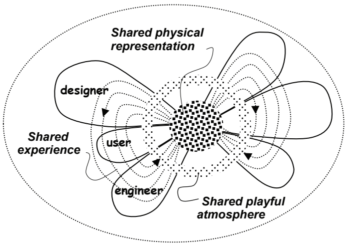

Figure 6.4. Model of a collaborative conceptualisation process with three collaborating actors

Figure 6.5 finally assembles the repeated efforts of a collaborative innovation team to reach shared understanding or meaning - or a conceptual solution where all individual actor views are represented and integrated. Individual mentalities are depicted as 'leaves' resulting in 'junctions' representing collaborative efforts, which can be evaluated (level) since they are modelled and shared by all actors through individual senses. Several efforts are made, evaluated, experimented with, negotiated and improved iteratively - some resulting in breakdowns and other bearing new ideas for improvements as basis for the next iteration. Ideation thereby becomes a process in dynamic focus flux between minds and world - and depicted as a (measurable) stem with leaves and a flower as the resulting solution (with seeds for next generation). The resulting metaphorical Plant of Collaborative Conceptualisation (PoCC) model suggests new terminology for central junctions: Visiotypes for early visions, Negotiotypes for collaborative draft models, Prototypes only for finished concept models and Seriotypes for market-test models. Like a plant, which adapts to the conditions where it grows, each PoCC model will have individual form. The five models are built from complex patterns of human consciousness. They are developed for professional innovation actors, basically uneducated in psychology, neurobiology and philosophy. The depictions can thereby serve as example of how vision sense stimulation can facilitate simplified understanding of complexity. The metaphorical PoCC model displays human preconditions for innovative conceptualisation - can it also prescribe principles for how a collaborative lab shall be organised and equipped?

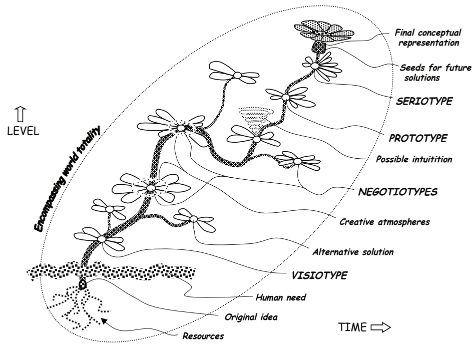

Figure 6.5. The Plant of Collaborative Conceptualisation (PoCC) model

6.4 A Lab for Perceiving Complex Conceptual Contexts

The PoCC model advocates: (a) dynamically repeated (external) sense-stimulations of conceptual aspects as the basic principle for (internal) idea generation, (b) iterative idea representations based on shared learning from stimulated experiences, (c) development of alternative concept suggestions which can be collaboratively experienced, (d) the inclusion and elaboration of all the actors' different mentalities in the iterations and (e) the importance of evaluating the alternative concept solutions in framings of wholeness.

The model was developed from case studies based on material Rapid Prototyping models, efficiently made from digital models. A new research question was now formulated: How can new digital visualisation technology further enhance the principles modelled in PoCC? In search of relevant answers some problematic characteristics of collaborative innovation processes were addressed - based upon many years of own experience in Norwegian industry: (i) *Complexity:* Updated co-innovation projects are based upon a multiplicity of data-file information formats, (ii) *Anarchy:* As the amount of data tends to 'explode', typical projects have a tendency to achieve a chaotic structure, and *(iii) Overview:* If the design aspect of alternative conceptual solutions is an issue of concern, detail implications have a tendency to demolish critical understanding of wholeness.

Therefore; in scenarios involving shared perception of actors with different backgrounds and schooling, the *visualisation principles* become highly relevant for a lab. The PoCC model prescribes alternative and iterative solution models. And the interaction between the co-actors will involve actions like evaluating different propositions, studying part-solutions, tentatively integrate part-suggestions, visually experiment with new combinations - and eventually trying to come up with radical concepts. *Comparability* then becomes a major challenge, including how data should be prepared and processed. This will involve aspects like the organisation and presentation of data aimed at: (1) Achieving and maintaining basic overview of complexity scenarios, (2) Developing visual comparability between different concepts, (3) Understanding the process stages behind each conceptual suggestion and (4) Organising and displaying data according to their basic nature.

Wodehouse and Ion (2010) have analysed the use of integrated groupware and digital libraries in collaborative design projects. They found that employment of such formalised procedures are basically considered as inconvenient in practical conceptual design work, not the least because they have emerged from librarianship rather than design - "and do not lend themselves to creating an explorative experience". Instead they suggest a number of flexible approaches like fast browsing for information sources (Internet *etc.*), emphasising the use of sketching, physical modelling and tagging of specific applications - "to allow the information to be used freely as stimuli in the generation of ideas". The analysis supports many of our basic intentions. But their premises were found to be based on employment of small data screens for information displays, thereby limiting the possibility of functional overview and fast data access. Our analysis ended up with a strategy at the opposite extreme, in accordance with the PoCC prescription of wholeness contexts. *Large screens* have a capacity to visually display large amounts of relevant background data. And it eventually emerged that displayed relevant data can be made *instantly available at a twist of the head*. The challenge then becomes how to organise data displays aimed at 'intuitive' perception - or so that it is instantly obvious for actors where to look for the support data of the problem in question.

To evaluate and compare between alternative conceptual propositions, each backed by much data, it appeared as essential to perceive the differentiated data as *ensembles* - in the sense that all data related to a particular solution should be presented as *one visual unit*. In evaluative discussions it would thereby be easy to distinguish between the conceptual alternatives.

Then came the problem of how to organise the display of each visual unit in an ‘intuitive’ way. It was found that the PoCC model can represent a relevant answer. It is built on an ‘archetypical’ concept for visual displays, at least in the western world, where the vertical axis represents *level* and the horizontal axis represents *time.* Gradually increasing conceptual level is thereby displayed visually along the diagonal. This invites to using this region for visual presentations of conceptual drafts - eventually leading to a negotiated concept proposition (*e.g.* 3D modelled) at the top right corner. But how should supportive data be displayed? Supportive data can be categorised in several ways, but hard-to-understand categorisations were seen as contra- productive. It was agreed that two simple categories will suffice: *abstracted* data and *concrete/visual* data. The lower right corner was assigned for abstract data (lower visual level) and upper left for visual data (higher visual level). Supportive data will then be perceived visually as supporting solution proposals which can be iteratively displayed along the conceptual diagonal. Figure 6.6 depicts an outline of one development story with relevant data and stages. It is intended as an easily understandable, or ‘intuitive’, visualisation of a basically complex conceptualisation process; a *perception map.*

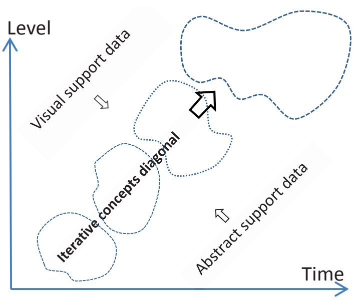

Figure 6.6. Easily understandable structure of one ensemble screen image, a perception map

How, then, should appropriate comparability between different perception maps be solved? It was agreed that a commonly shared experience from PowerPoint presentations should be avoided: the removal of slides after each display leads to ‘wasting’ focus on trying to remember data instead of using mental capacity for conceptual processing of the data. If perception maps of alternative solutions are placed *beside each other* instead, then instant comparisons between the central visualised aspects of each proposition could be easily facilitated - for all actors to see at a twist of the head. What aspect to focus could be achieved through equipping the actors with some pointing device. How could such a large-screen scenario be practically arranged?

Maritime simulators were eventually found to have potential attributes to comply with the specified functional characterisations. They consist of (split-up or coordinated) central projectors displaying visual projections on a large circular vertical screen - up to 360 degrees. Several conceptual perception maps (Figure

6.6) can be displayed consecutively, one at the time, beside each other. Each visual unit is then easily distinguishable from the alternative concepts represented on the neighbouring projections. And neighbour projectors can additionally be coordinated, *e.g.* for aspectual 3D modelling. A highly flexible arrangement thereby results.

For the realisation of a co-lab according to these specs, a 360 degrees barrel-shaped geometry of 11 metres diameter and 4 metres height and seven projectors was chosen (eventually called *SimSam lab)*. As a SimSam case example can serve a co-design process where three alternative propositions of a redesign project shall be elaborated. One projection displays the design brief/framework, three separate projections display perception maps of each concept, one projection can display new concepts-in-the-making and two coordinated projectors display 3D simulations of selected details, one at the time. Coordinated projections are also appropriate for static/dynamic simulations of selected design issues. See Figure 6.7.

Figure 6.7. Outline example of unfolded 360 degree barrel screen with seven split-up or coordinated projections displaying perception maps (Figure 6.6) of three conceptual propositions plus work spaces for co-creating new solutions.

The actors are placed on the floor near the screen centre. All screen images (Figure 6.6) are simultaneously comparable beside each other to optimise visual understanding. Simply in turning, standing or sitting on rotatable chairs, and pointing with laser pens all displayed scenarios are available, instantly and easily perceivable, for on-the-spot shared elaboration by all the actors, see Figure 6.8.

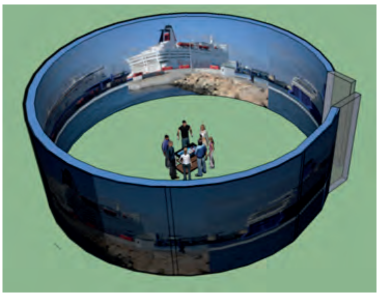

Figure 6.8. The resulting SimSam lab outline with coordinated or split-up projectors

Understanding from the PoCC model has thereby led the development to a physical arrangement where the need for large screens can be seen as a consequence of the need for rapid comparisons and integration between complex visual data of alternative concepts. Additionally large screens have high capacity for *3D simulation*. Turkle (2009) has suggested how simulations can stimulate body/mind experiences of future concepts in context - through the 'Immersive systems' approach. This strategy was adapted as a process extension aimed at elaboration of conceptual specificities. Figure 6.9 displays an early experimental collaborative workshop for development of alternative harbour scenarios, where 3D simulation including three coordinated projectors is displayed. Figure 6.10 shows a following health-care workshop based on ensemble projections of alternative concepts in accordance with Figures 6.6 and 6.7.

Figure 6.9. 3D harbour simulation

Figure 6.10. *Healthcare co-development*

A new challenge then becomes: How shall the scenarios be organised in terms of operational visualisation characteristics and tooling?

6.5 New Sense-stimulating Conceptualisation Technology

Support data will generally be of diverging visual expressions that are not appropriate for supporting a Fig. 6 outline, whereby *reorganisation* becomes desirable. Central perceptual aspects with importance for choice and capacities of appropriate support-tools were specified accordingly: (A) *Organisation:* data-based statistics, graphs, quantifications and pictures, should be properly organised for comparable discussions, (B) *Categorisation:* data should be grouped according to their conceptual relevance, *e.g.* functional, quantitative, qualitative, detail and (C) *Scaling:* files should be easily scalable to comply with perceptual claims.

Supportive controls and drawing tools were evaluated for their visual conceptualisation support, including: (a) *Participation:* Capacity for new or add-on sketching contributions by all actors regardless of competence, (b) *Speed:* Time compression because people have a tendency to loose mental focus fast, (c) *Changeability:* Capacity for fast changes of visual representations, (d) *Interchangeability:* Capacity for flexible altering between different 3D and 2D software and (e) *Simulation capacity:* Potential for static and dynamic 3D simulation.

Could technology be found which is adaptable to these perception-based operational characteristics? *New touch- or multi-touch technology* builds on perceptual stimulation as such, and it was early considered to be highly relevant. The technology employs scanning of touch impulses on a screen (*e.g.* fingers), where the registered signals are digitised and can be employed for sense-stimulating facilitation. See Figure 6.11.

Figure 6.11. Participative drawing on multi-touch table

In up-front testing and evaluations touch technology was found to comply with the above specified operational preconditions. It was found highly appropriate for rapid and effective organisation of data files, in particular for visualised files including graphs, figures, photographs, statistics etc, but also for abstracted data. It was easy and fast for data manipulation, including categorisation, grouping for relevance and scaling. And it was found exceptionally well suited for arrangements and presentations of ensemble screen images, or *display organisation,* in accordance with Figures 6.6 and 6.7. So-called bi-directional (BiDi) technology has possibility of recognition of objects on the surface ('tagging'), which involves that material objects, hand-operated upon the screen, can interact with data models through digital addressing. Physical models can be moved and played with (*e.g.* by role-playing actors) in sense-stimulating digital landscapes.

Multi-touch screens were also evaluated, with different software, for their ability to become a functional platform for digital drawing. The test showed that touch-screens employed for drawing exercises and combined with large-screen displays, appear to have a very high potential for enhancing conceptual understanding according to the above specified claims. Screen employment can be time-efficient, rapid sketching can be easily facilitated, fast changes between wholeness and detail aspects can be easily achieved and changes between software packages can be done effortlessly - with high capacity for 3D design and simulation.

An important finding was that a touch table is appropriate for allowing several actors to participate in drawing actions towards shared understanding (Figure 6.4). Actors can easily assemble round a table and contribute to *participative drawing* through finger-touching or with a touch-tool, to stimulate integrated contributions by all participants - regardless of drawing competence. This level of participation cannot be achieved in traditional drawing, which is basically dependent upon the skills of one drawing actor and her ability to interpret others actors' mentalities.

The efficiency of the described visualisation scenarios is, of course, highly dependent upon the capabilities and competence of an operator. It was accordingly specified that SimSam lab activities should be led by a *facilitator*. A facilitator should have high competence in operating all the tools including several appropriate software packages. One important operational aspect will be, in advance of collaborative workshops, to prepare alternative conceptual ensembles in accordance with the pre-established outlines of Figures 6.6 and 6.7. Another important assignment will be to stimulate engagement between the actors through visualisation and integration of *their* mental images - in addition to her own.

Supportive materialisation tools were additionally found desirable for fast and functional facilitation. In accordance with Capjon (2004) Rapid Prototyping tooling and 3D laser scanning were integrated for their great ability of physical sense stimulation and features like speed, specificity and reversibility. In addition workbench facilities for *mock-up production* were integrated, with materials like card-board, wire, clay, foam etc, for additional enhancement of sense stimuli. Figure 6.12.

Figure 6.12. Early full lab model equipped with large screens, touch-table interface, 3D printing, mock-up facilities and 3D scanning

6.6 Conclusions

Humans conceptualise ideas through active perceptual stimulation of their senses - as elaborated and displayed in the metaphorical PoCC model. The model was used as a template for an analytic design process of a new collaborative lab concept.

Perceptual complexity problems of current co-development processes were solved through PoCC-like *perception maps,* where easy comparability between alternative concepts is achieved through standardised graphics. Immediate access to diverse data for elaboration purposes and integration between alternative concepts were solved through *large screens* of a maritime simulator with side-by-side map arrangements and laser pointers for all the actors. Large screens were also found appropriate for *simulation* of future conceptual scenarios in context. Sense stimulation in collaborative conceptualisation was achieved through employment of a large *multi-touch table*, through which *participative drawing* and *display organisation* were facilitated by a facilitator with appropriate visualisation competence.

Table 6.1. Summarised features of a SimSam-supported co-innovation process

Developmental phase	Sense stimulation	Physical realisation
Organisation of premises	Visual preparation of data	Laptops before meeting
Arrangement data availability	Immediate access to data	Large screens, 360 deg. simulator
Grouping in alternative conceptual ensembles	Simultaneous comparability between concept suggestions	Side-by-side displays
Intuitive arrangement of each alternative	Conceptual diagonal displays + supportive data from sides	Immediately comparable perception maps
Rearrangements of part solutions	Model developments + participative drawing	Mock-up facilities + fast digital drawing with software
Elaboration of new concepts	Simulation, rapid 3D models + physical realisation	Touch-table with software + 3D printing (RP)
Verification of best concept	Sense-based experimentation with alternatives	Facilities for simulation and physical experiments

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Publication 3

EMERGING TOOLS FOR CONCEPTUAL DESIGN: THE USE OF GAME ENGINES TO DESIGN FUTURE USER SCENARIOS IN THE FUZZY FRONT END OF MARITIME INNOVATION

Snorre Hjelseth
Faculty of Technology and Maritime Sciences
The Oslo School of Architecture and Design, Vestfold University College
Raveien 197, Borre, 3184, Norway
E-mail: snorre.hjelseth@hive.no

KEYWORDS

Design, Conceptualization, Simulation, Maritime innovation.

ABSTRACT

This paper discusses and describes how simulated user scenarios can be created and used in the front end of maritime innovation processes. The paper introduces the use of game engines as design tool to create dynamic scenario environments that are used as means to facilitate interdisciplinary collaboration between users and actors in a design process. The goal of the research was to see if it is possible to integrate realistic real-time simulations with user input in the conceptualization phases of innovation. The paper describes a micro case from the maritime industry that shows some of the complexity levels regarding the understanding of user scenarios in interdisciplinary design groups. The second case study reports on an ongoing development project where simulation has been used to explore crisis scenarios in the Oslo fjord. The results show that the use of design thinking and user involvement in combination with simulation tools can create a platform for an iterative process to develop complex user scenarios that drive conceptual innovation.

INTRODUCTION

Conducting user centered design in the Fuzzy Front End (Koen, 2004) of maritime innovation is a challenge. The fuzzy front end refers to the process and activities that comes before the more structured new product development process with traditional stage gates (Cooper 2001). If designing is about "changing existing situations into preferred ones" (Simon, 1981), understanding situations or scenarios is a key element. Problems concerning users are often 'wicked' (Rittel et al, 1973) or ill-defined because factors and solutions are often unknown (Lawson, 2005; Lawson and Dorst, 2009). Dealing with these types of problems often requires a more radical approach in contrast to incremental development where the goals are often increased product performance.

In order to explore and understand such unknown factors, designers need approaches other than what is currently the practise in the maritime industry. In addition, one of the bottlenecks for implementing new types of conceptualisation processes in the industry is the complex nature of maritime innovation on multiple levels. These include:

- Design and development are often dependent on collaboration between multiple companies within a maritime cluster
- The maritime contexts at sea are often not available for experience by the designer
- Products and systems often contain a range of different technology
- Carrying out task analysis is often a challenge because of the complexity of operations
- Testing new concepts is often not possible because of matters of safety and risk.

Emma Linder (2008) and Jan Inge Jenssen (2003) describe some of these innovation challenges.

The first part of this paper explores some of these challenges when effecting user centred design through a case study where a new seismic simulator was designed. Through participatory action research and qualitative interviews we explored answers to the following question: How is it possible to understand and analyse complex user scenarios via simulation in the maritime and offshore industry?

Based on results from this study we proposed a game engine tool to simulate scenarios that can be created in the design conceptualisation phases of the activity. The porous character of this tool lay in the ability to create and visualize complexity in a way that more easily allows designers to obtain a holistic overview and enable fast design modifications.

Existing research about the use of simulators and VR tools in early product development phases shows that user scenario simulation improves information quality and quantity from end-user feedback that can identify usability issues (Thalen, 2011). However these areas tend to focus on creating life-like interface experiences for user evaluation and not on the potential as an iterative design tool.

When these types of tools have been used for conceptualisation in design processes they often only utilize the real-time rendering engine to walk through static 3D models. The *Lumion* simulation software is an example of this. This application of the tool might cover the needs of architects designing buildings to develop an more immersed experience of a design concept, but it offers little flexibility when designing for complex maritime tasks or operations where a more dynamic approach to behaviours is needed. The central question this paper tackles is how game engines might be used as a design tool to visualize and simulate user scenarios for conceptualisation in maritime innovation.

MARITIME INNOVATION AND INDUSTRIAL DESIGN

The maritime industries often have a conservative approach to innovation strategy that is lodged in decades of experience. This industry typically uses engineering methods to design and solve most of its problems. These problems are mainly technical or systems oriented where human input is a sub-factor of the overall innovation strategy.

Innovation and operation in the maritime sector have seen increased interest in human safety and operation performance. If a human focus is needed in design, it is often referred to as human factors or ergonomics (Meister, 1999). The problem with human factors in the maritime sector is that its not implemented in the core design activities in the innovation processes that are undertaken. The reason for this is that engineers are not trained in designing for user experience or with human factors orientation. Human factors are then often seen more as requirements than innovation possibilities. This gap in competence in the maritime innovation process has opened up possibilities for industrial and interaction designers with special competencies in design thinking, engagement and user centered design.

Recently, some projects in the maritime sector have included industrial designers as part of their core innovation strategy. The K-Master operator chair (Figure 1) project carried out by industrial designer Magne Høyby in Hareide Design is a good example not only of how design thinking and human factors can be part of an innovation strategy, but also how the design process itself can manage the conceptualisation phases in collaboration with technical engineers.

Figure 1. K-Master operator chair designed for Kongsberg Maritime by Hareide Design

SIMULATION

Simulation tools are often used in late stages of innovation where tests are made to evaluate a finished design. When human factors are simulated, tests are often performed in simulators that are costumed designed for training purposes. Simulators might be very useful in user evaluation and in usability testing, but they are often not used until later stages in the development process where changes of the design are costly.

One challenge with simulation software is that it is not designed to be used as a tools in conceptualisation processes. Creating simulations can be time consuming where considerable programing must be implemented even to do simple task such as importing 3D models. Often these types of programing tasks are preformed in low-cast representations.

3D CAD tools have eventually become crucial in product development, but the tools are not basically designed for creative cross-professional design processes, where “changing existing situations into preferred ones” (Simon, 1981) is at stake. Laurel (2003) describes how visualisations and models are created to simulate future scenarios that are often used in the final presentation of concepts and not as creative tools in the conceptualisation phases when designing.

The idea of using 3D game engines as a tool in the design process is to improve the ability to understand existing and develop future user scenarios much earlier in the design process (Tideman 2008; Thalen 2011; Manninen 2000). There are several types of game engines on the market and the most popular is *Unity*, *Unreal engine*, and *CryENGINE*.

A game engine is a software framework that is used to create games for platforms like *Xbox*, *PlayStation* or personal computers. Typical functionalities are 2D or 3D graphics-rendering engine, object collision detection, physics engine, animation integration, artificial intellegance, sound integration, scripting and network extensions. All these functionalities can be simulated simultaneously to create realistic game experiences. Such tools can be used to simulate existing and future user scenarios in development of products, systems and services.

Simulation needs immersion and immersion allows the user to experience the simulation in a way that stimulates possibilities that otherwise would have been impossible (Turkle 2009). Squyres (2006) describe such simulation cases that have been designed on screen, like structuring molecules in virtual space, nuclear explotions and controlig a romotly operated vihicle on Mars. At the same time as immersion is beneficial it makes one also vulnerable if the model and outcome are not seen with critical eyes (Turkle 2009). Immersion has seductive capabilities that overshadow the real implications of simulation.

In the case described in this paper there are two levels of immersion. One is the software visual simulation it self that aims to create realistic representation of the scenarios, and two the screen system that displays the simulation. Both are important in order to create the overall immersive experience of the simulation.

Design places like the *Envisionment and Discovery Collaboratory* have been made in relation to dealing with human computer interaction and simulation systems in collective design process (Arias 2000). The idea is to create a system where an interdisciplinary team will more easily address implications based on their background from a shared visual perspective.

This can be realised by drawing on the notion of co-design (Sanders and Stappers 2008) and participatory design (Ehn and Löwgren 1997). In these approaches where externalisations of ideas and knowledge are made to create shared understanding and facilitate collective creativity (Sanders and Rim 2001) between interdisciplinary actors.

Figure 2. Jernbaneverket shows different alternatives for new railroad tracks using visual simulations in the SimSam-lab at Vestfold University College.

In this research we have been using a visual immersive system *SimSam* (Figure 2) that allows a team of actors and users to experience the simulation simultaneously in a design place (Jan & Hjelseth 2012). The wide angle of the screen covers more of the view angle of the actors and gives stronger sense experiences that raise the level of immersion. This can sometimes have negative effect where the actor feels seasick. The CAVE [Cruz-Neira et al., 1992], is another example of an visual immersive system designed to explore and interact with virtual environments.

The most common argument for why these tools are used in product design processes is that the software itself is oriented towards software engineers and that the game engine editors require a great deal of programing code. The trend in the development of game engines is to create editors with interfaces that do not require a lot of programing and that it is possible to create simple games and simulations with a minimum knowledge about codes (Kraus 2012). With the introduction of touch interface devices like the iPad and the iPhone there has been an increasing interest among designers to use 3D game engines to create tangible applications. The Oslo School of Architecture and Design has now integrated game engine tools as part of their master courses in interaction design in order to explore the use of such tools in design practice.

RESEARCH METHODS

An explorative research methods was used in case studies to develop and explore the simulation and simulation tools in relation to design processes. This was based on existing methods and knowledge about the use of scenarios in design conseptualisation phases, co-design and 3D software expertise. In the cases presented here this author researcher has been actively involved in the design activities that have been placed within a methodology drawn from participatory action research (PAR) (Hult and Lennung, 1980; Denzin and Lincoln, 2000). Through the use of PAR it was possible for the researcher to get an holistic experience of the process when designing the simulations and its relevance when used in a co-design workshop with multiple actors.

Empirical data based on observations during design workshops was produced through the case studies in real-life situations (Yin, 2009). The obervations focused on the way the simulation and the simulation tool was used by the designer and particepaticipants during these workshops. It was observed how actors established a shared scenario understanding, created analogies to other scenarios, and how ideas or suggestions to change were stimulated.

The engineers, project maneger and customers in the PGS case study were interviewed using a qualitative interview method (Kvale and Rygge, 2009). This interview method allowed for a subjective and personal insight in the actors' own experience of design tools used in the design process.

DESIGNING THROUGH SCENARIOS

Referring back to our qualitative interviews with Kongsberg Simulation, one of the leading simulation companies in the maritime market, we have seen been increasing interest in the maritime and offshore market to simulate future scenarios. One of the goal with this type of simulation is to get a full overview of the scenarios so unknown factors can be discovered and solved.

Implications of carrying out user studies in the maritime domain have been researched through a micro case study in a design process of a seismic streamer recovery simulator at Kongsberg Simulation. The starting point for the design team was a technical system oriented approach to understand the recovery operation. The problem with this approach was that the user's perspective was not addressed at this early stage and was supposed to be implemented later on in the process. The design team found it hard to understand the user scenarios based on written description from users with pictures and small video clips. This “task oriented” method is being applied in their more incremental processes where small changes are done to existing products. The problem of obtaining a shared understanding between the engineers delayed the whole project for six months. To understand the scenarios from a user's perspective, a new approach was needed. In order to obtain a better overview of the whole process we placed five action cameras on different positions and two of them where mounted on the heads of the winch-operators. Through this multiple angle view (Figure 3) it was possible to link the users' tasks to the overall recovery operation scenario.

Figure 3. Video of the seismic recovery operation with multiple view angles showing overall operation view, and tasks performed by crew and winch operators.

This design process showd that it is difficult to understand complex scenarios in the maritime industry. The interviews from this case study showed that the ability to have multiple view angles gave a much better understanding of the scenarios complex user scenarios. One interviewee, for example, mentioned that the video material was very important to help everyone to understand what was happening and that having good video material is not to be underestimated when trying to understand this type of operations. A more detailed description and analysis of the interviews will be published in a future article.

Findings

A number of findings were drawn from this study. These were that:

- User tasks in maritime and offshore operations are often complex
- Existing float diagrams are sometimes to complex to get a holistic overview of the user task
- The float diagram has a problem of creating a shared understanding within the design team.
- Collecting user information trough probes did not give a satisfied overview, and tacit user knowledge was not implemented
- A combination of video and user involvement improve understanding of the user tasks
- Multiple view angle cameras provided the means to understand simultaneous operation in a holistic view.

ONGOING CASE STUDY: SIMULATING CRISIS SCENARIOS IN THE OSLO FIORD

The background for this case is is the development of a new ferry concession between Horten and Moss in the Oslo fiord. In the new concession it is proposed that number of departures be increased in response to increased vehicle traffic. The ferry line is already the most profitable in Norway. Yet, the Norwegian Coastal Administration has reported that the Oslo fiord is the most hazardous coastline in Norway. The development group Maritime Competence Oslofjord (MKO) is a combination of different companies that have started a project to look at different risk factors in the Oslo fiord that opens for new product, services or business opportunities. The project has been developed and facilitated through workshop meetings with interdisciplinary participants.

The first workshop was about finding existing risk scenarios and possible future risks with the increased ship and ferry traffic. Part of this workshop included participation by former captains, vessel traffic central (VTS), ship pilots, Norwegian Maritime Education (NMU) and the Norwegian Coastal Administration. To facilitate discussion we used acrylic ship models on a Microsoft Surface screen where we displayed different types of maps and AIS information (Figure 4). The participants used the models as boundary objects to explain different risk scenarios (Figure 5). These typically include tangible objects that can be transformed or arranged in order to communicate ideas or knowledge. Examples are: clay models, foam models, drawings, paper mockups, CAD models, rapid prototypes or pictures.

Figure 4. Actors interacting with ship models on a multi-touch screen.

Figure 5. Acrylic ship models.

After the workshop different risk scenarios were simulated in the game engine. The surrounding landscape was auto-generated in 3D using data from *NorgeDigitalt* and also textured using pictures. The boat 3D models were downloaded from Google Warehouse and imported into the game engine with existing boat-vehicle scripts that allow for AI behaviour, collision detection, physics and hydrodynamic properties.

In the second workshop (Figure 6) the goal was to explore the risk scenarios and discuss possible ideas and solutions. Different local companies, organisations and ship captains represented the assembled and key actors.

Figure 6. Interdisciplinary actors discussing possible VTS applications when using the simulation as means to stimulate discussion in the second workshop.

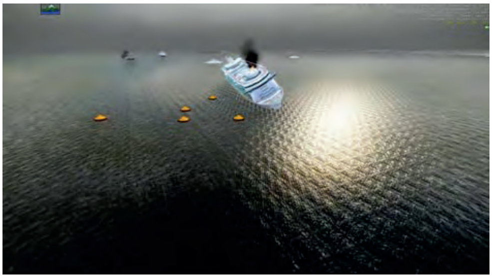

Figure 7. Crisis scenario in which a cruise ship has hit a containership in the Oslo fjord.

By using the simulated scenario (Figure 7) the captain explained the different risk scenarios to the other actors. The scenario took place before, during and after ship accidents. Through the game function it was possible to play different crisis roles that were part of the scenario. The game function enabled better user participation where participants could play an avatar role to share their knowledge end experience.

When a scenario is created it is possible to include multiple user inputs in combination with artificial intelligence and avatars. Consequently, design workshop participants play roles as captain, passenger (Figure 8), ship, crew, rescue boat or rescue helicopter (Figure 9) in the same scenario. This allows for a better understanding across disciplines and experiences, and offers a means to visualize and interact with the complex nature and processes of the crisis.

Figure 8. Avatar view from passenger who has jumped into the water.

Figure 9. The avatar view from rescue helicopter when approaching the sinking ship.

Based on the simulation, the design actors then created ideas and new concepts on VTS systems, crisis management plans, new training courses and automated ship docking systems. The aim of this move in the process was to create a collective understanding of the different user roles and to see how they influenced the overall crisis. This enabled new approaches to understand the crisis scenario from different user perspectives and inspire new ideas for innovation.

DISCUSSION

The results of the first workshops show that it is possible to use the game engine as an iterative design tool for design conceptualisation. One of the most important functions to the tools used to create concepts is the ability to utlise a fast workflow. The use of ready-made 3D models makes this workflow easier, but if the design project requires a lot of custom modelling it might create a bottleneck in the work pipeline.

The fuzzy front end of innovation is never predictable and the use of design tools changes according to problems, actors and context. To use game engines to simulate scenarios in a design workshop is relatively more complicated than working with low-fidelity boundary objects like physical mock-ups, cardboard models and rapid prototypes. Tim Brown (2008) argues that:

Prototypes should command only as much time, effort, and investment as are needed to generate useful feedback and evolve an idea. The more "finished" a prototype seems, the less likely its creators will be to pay attention to and profit from feedback. The goal of prototyping isn't to finish. It is to learn about the strengths and weaknesses of the idea and to identify new directions that further prototypes might take.

The initial phase of using the game engine to create the scenarios is more time consuming in relation to more traditional methods, but the iterative process is very fast because of the layered based structure of working with 3D models in real time environments. Adding new items and modifying the scenario is much faster when the initial phase of creating basic elements are in place.
The rendering technology used in the game engines creates automatic hi-fidelity realistic images that might give the feeling of more finished result; it has not shown any negative effects when ideas to concepts are created. However if the simulations have behavior error or digital artifacts it might draw attention.

On a more negative note, the use of game engines might not be suitable as a design tool in all contexts in the fuzzy front end, however, more optimostically, it has shown to be valuable in the conceptualization phase in maritime innovation.

CONCLUSION

Maritime innovation processes are complex and may require different and untraditional approaches when designing for diverse users who face different degrees of complexity and situations of ease and risk. However, the industry often lacks competence in how to fulfill user centered design, and human factors are often seen more as requirements than innovation opportunities. As an early counterweight to such perspectives, this paper describes some of the complexity levels regarding user centered design in maritime innovation.

The use of game engines to visualize and simulate existing end future user scenarios in the design conceptualisation phases were introduced. The results from what is still an ongoing case study show that it is possible to implement this tool and that it allows an iterative conceptual approach within the front end of innovation. The actual tested scenarios and simulations provided experiential settings and contexts of collaborative engagement and dialogue that offer alternatives to building richer understanding of the complexity of contextual activities on the sea.

Using simulated behaviours and artificial intelligence in combination with realistic visualizations enabled our small experimental group of interdisciplinary design participants to develop fuller and more holistic overviews of complex scenarios. In addtion - and importantly for design in the martime sector - the usability friendly interface of the game engine enabled the designer to modify and add the simulated scenarios during the design workshop. The tool also allows expert users to share their knowledge and experience through the role of an avatar in the scenarios that improves feedback information quality and quantity.

Taken together these design rich aspects of involving simulated uses in critical settings in the maritime sector may help enhance our perception and responses to fiend critical experiences and emergent an given needs. There would appear to be further room to investigate the role of design in the fuzzy front end of wider innovation processes in the sector so as to improve consistency and clarity in safety, operations and shared activities that unfold in contexts of use.

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AUTHOR BIOGRAPHY

Snorre Hjelseth in as industrial designer with special interest in design thinking in the maritime and offshore innovation sector. His PhD research focuses on visualization and simulation as means in interdisciplinary design processes. Snorre is part of the SimSam-lab development project at Vestfold University College (HiVe) where an immersive system has been developed to help facilitate design workshops. He received a Master’s in Industrial Design from the Oslo School of Architecture and Design (AHO), and the Indian Institute of Technology Bombay (IIT). He is now a PhD-fellow at AHO with a position at HiVe.

Publication 4

Design and computer simulated user scenarios: Exploring real-time 3D game engines and simulation in designing in the maritime sector

Scenarios are useful tools for investigating interactions between users, equipment and context over time. Designers often use scenarios to approach complex design problems in a holistic manner. However, the efficient use of scenarios can be a challenge in complex dynamic user contexts due to mediation and tool limitations that use traditional scenario techniques in design practice. This article investigates the use of real-time 3D game engines on the part of interaction/product designer-researchers as a design tool to conceptualise and simulate possible future shared user scenarios in the maritime domain. Three exploratory and qualitative case studies are described and discussed that draw on collaborative and participatory design in the frame of action research and research through design. Results from the cases reveal that real-time 3D game engines can simulate multiple complex behaviours that otherwise would have been impossible to materialize with traditional visual scenario or storytelling methods. This opens up new possibilities for how designers can handle complex user relations and related risk factors when designing. For the maritime sector this has further potential for the handling of safety critical operations.

Keywords – Design Tools, User Centred Design, Simulated Scenarios, Game-engines, real-time

Relevance to Design Practice – This research shows how designers can handle maritime design challenges of complex systems in relation to *User-Centred Design* where game engines offer new potential for materialising future simulated scenarios.

Introduction

Setting the stage

Human failure is by far the largest contributor to maritime accidents (Rothblum, 2000; Bjørneseth et al., 2008; Grech et al., 2002). In the maritime industry there is a move towards including User Centred Design (UCD) processes (Gould & Lewis, 1985; Norman & Draper, 1986) in an effort to ensure safer operations at sea (Mills, 2006; Hukkelås, 2013). The maritime sector deals with safety critical operations where a range of systems, equipment, vessels and personnel collaborate in complex operations. In designing for such operations, designers need to deal with multiple levels of complexity in contextually related systems. This makes it central to clarify ill-defined problems in the early design phases and in front-end of innovation where ideas and concepts are posed. This article takes up the use of real-time 3D game engines as a design tool by interaction/product designer-researchers in order to simulate possible future shared user scenarios in the maritime domain. This innovation perspective shifts attention away from human factors approaches to conceptualisation and simulation in design practice and inquiry.

Concerning UCD in maritime settings, a major challenge for the designer is to holistically understand the needs and actions of users and use practices in terms of both context and systems. Computer simulation and related scenarios provide ways to approach such complex relations in UCD through the simultaneous simulation and visualization of several systems and behaviours (Winsberg, 2010). A scenario can be described as series of hypothetical actions and events (Bødker 2000). Broadly, simulation refers to the modelling of real world situations via representational, meditational and, increasingly, computational design techniques. Applying computer simulated scenarios to UCD is not straightforward and it is difficult to model human experiences for use in simulation. Therefore, when deploying computer simulation in UCD, there is a need to develop rich and pragmatic approaches that connect human actions with technologically mediated renderings.

As response to the potential of scenario simulation for UCD processes in the maritime sector, we investigated modelling and simulating user scenarios using a game engine. A game engine is a software framework used in the process of creating and running computer games. The game engine renders that which enables the game experience in the game world: it does this through modules of technical infrastructures (Nideffer, 2003). Simulation software is part of the game engine's running of game functions or the mimicking of real world behaviours based on mathematical models.

In our approach we explored the use of game engines and simulations through the process of exploratory investigation through case studies in the maritime domain. We examined how computer simulated scenarios can be used as means to facilitate a maritime design process by exploring and revealing possible design solutions and problems related to three issues: risk, safety and operations. Through three cases we addressed two key questions: 1) how *computer simulated user scenarios* may be used as means to facilitate a design process to explore and reveal possible design solutions and problems in the maritime sector, and 2) how *a game engine* may be used as a design tool in user scenario development to facilitate design for complex systems and contexts.

The first case study explored a possible increase in the traffic of ferries in the Oslo fjord in Norway as a result of the granting of new ferry concession in 2015. The second case study dealt with the multiplication of challenges for supply ships operating in the polar areas. The third case concerned a new light design system for helidecks on semi-submersible drill rigs. The participants involved in the collaborative design sessions of case studies included designers, expert actors and users. The designers are people who perform design activities, expert actors are defined as specialist personnel or a specific discipline, and users are persons that are to interact with the design situation, product or system, directly or indirectly.

Several research articles that report on the use of game engines and simulation with a focus on humans in a design process are relevant for the contexts covered in this article (Aldoy & Evans, 2011; Kuutti et al., 2001; Mikchevitch et al., 2005; Manninen, 2000; Tideman et al., 2008; Gabbard et al., 1999; Zoltán et al., 2007; Kumar et al., 2011). However, these approaches mainly focus on the use of simulation for user tests and evaluations of products and prototypes as part of a design process. User tests and product evaluation processes need to focus on the validation and verification of simulation results, such as in natural and social science (Winsberg, 2010). Our work differs in using simulation in the conceptualisation phases of design. This work is geared to support exploration of the design space and problems and solutions therein before design testing can be effected. We believe this shifts attention to a more convergent perspective of understanding and exploring in an early, conceptual phase of designing that is often needed to re-frame initial ill-defined design problems.

Other work exploring simulation and game engines for learning and training is usually gathered under the titles *serious games* (Liu & Ding, 2009) and *gamification* (Deterding et al., 2011). Some of this work is related to human factor research: simulations of human-machine interactions use techniques such as walk-throughs and talk-throughs (Meister, 1986). Further, simulators have been used for the analysis of human errors in the operation of nuclear control rooms (Beare & Dorris, 1983), helicopter task analysis (Hess et al., 2002) and for examining driver performance (Cacciabue et al., 2007). NASA uses simulation to create future scenarios on planets like Mars. Simulation is used to test and train for space missions using Remotely Operated Vehicles or ROVs (Piovano et al., 2012). Simulations and game engines are also employed as a collaborative platform in Computer Supported Collaborative Work (CSCW) for system engineering (Wang et al., 2010), agent-based simulation (Zhang at el, 2008) and in creating a collaborative setting for multiple network administrators (Harrop & Armitage, 2006). Game engines and simulation appear in the application of Virtual Reality (VR) techniques in UCD (Thalen & Voort 2012); they are referred to as virtual prototyping in product development (Schaaf & Thompson, 1997). Augmented Reality (Azuma, 1997) uses different simulation techniques and game engines, such as 'situated simulations' (XXX & XXX, 2014) that combine real world and real time images with virtual environments on mobile devices.

Drawing on such diversity in the application and research of simulation, this article investigates how simulation can be applied to UCD to explore problems and issues that are related to user needs and experiences that are part of complex operations, contexts and systems in the maritime sector. We believe that the ability to handle such user related complexity using game engines in the maritime design domain is novel and can help position UCD as having a central and much needed role in the sector by placing more design based focus on human risk and safety issues in the early, conceptual phase of design.

Approach and outline

In our research inquiry we have carried out a practice-oriented process akin to action research (Archer, 1995) and 'research through design' (XXX & XXX, 2010). Such approaches relate theory to practice and connect documentation with analysis. Through three applied cases, computer generated simulations are used as a tool for co-reflection between a user and a designer who facilitate a discursive process through real-time manipulation of the scenarios. Our work refers to design research into shipping and to offshore design challenges in three settings: 1) concerning crisis management in a busy navigation channel (shipping), 2) dynamic positioning in the polar areas (offshore) and 3) helicopter deck design (offshore and shipping). Throughout the process of our inquiry we have collected and contextualised observation material from these cases based on scenarios and via a variety of design ‘representations’, ranging from design sketches to fully formed, large-scale simulated scenarios. The data was collected by means of screen captures and video recording of collaborative design sessions along with participant observation and on site interviews with participants.

Below we offer an overview of scenarios and simulation. We then present and analyse the data gathered by exploring aspects of the computer game engine as a design tool in relation to scenario mediation, simulation, collaboration, reflection-in-action and related research areas. The article closes by offering a design centred view on computer simulated scenarios in the maritime sector through exploring real-time 3D game engines and simulation in a user-centred perspective. As a whole, the article blends interaction, product and systems design that is oriented to the maritime domain. This is a massive global and commercial sector in which there is still little such research and the article closes by discussing these needs and some directions for future research.

Scenarios, Simulations and Game Engines

On scenarios

Different types of user scenario methods are often used in UCD processes when designing for user experience, such as staged play sessions (Simsarian, 2003), storytelling (Lerdahl, 2001), exploratory design games (Brandt, 2006, p. 59) and experience prototyping (Buchenau & Suri, 2000). Through visual storytelling (Buxton, 2007, p. 277), designers can visualize sequences or animations of the user, use, objects, behaviours, events and interaction, in context and over time. This enables the designer to explore the different relations between factors and help frame and re-frame problems.

Scenarios are used in several different contexts and have various meanings in the fields they are taken up. In Human-Computer Interaction (HCI) Carroll (2000) referred to scenarios as the “stories about people and their activities”. (p. 46). Visser et al. (2005) claim that “When important decisions have to be made, a clear and convincing argument can be made using a scenario of the interaction based on the design and the knowledge about its context” (p. 135). In the maritime sector, scenarios have traditionally been used in training (Barnett et al., 2003), such as emergency and crisis management for situation awareness or task analysis in complex engineering operations (Maslin, November 2013).

On Simulations

For Banks (2011), “A simulation is an applied methodology that can describe the behaviour of that system using either a mathematical model or a symbolic model. Simply, simulation is the imitation of the operation of a real-world process or system over a period of time" and often used "… when the real system cannot be engaged" (p.6). Physics simulation uses mathematical models of real-world physics, such as atmospheric pressure, gravity, mass and density. In Artificial Intelligence (AI) simulations are entities with pre-made behaviour actions or responses. Simulation can also be adopted to create a dynamic model to explore a scenario. In UCD this is apparent in experience prototyping (Buchenau & Suri, 2000), or the simulation of ergonomics in a "Third Age Suit" (Hitchcock & Taylor, 2003) where young people can experience having the body of an elderly person.

A system that is simulated can include and exclude humans in the design and experience loop. Simulations with the 'human-in-the–loop' are often used to analyse systems operated by a human or for training purposes (Narayanan & Kidambi, 2011) Human-in-the-loop simulations are often related to human factor requirements were it is impossible to computer model and simulate the human input. A real human is therefore needed in the simulation model (McKneely at el., 2001). 'Serious gaming' is also a research area that takes up the combination of game engines and simulation for the purpose of developing skill and knowledge about contexts that are unavailable in a normal learning environment (Susi et al., 2007).

Computer simulation has enabled designers to deal with the complexity of design decisions in which theory and design can be experienced immediately. Winsberg (2010) argues that "Computer simulation is a method of studying complex systems that had implications in almost every scientific study – from quantum chemistry to the study of traffic–flow patterns" (p. 4). Examples abound on using computer simulation for usability testing in product development. Among the topics covered are virtual prototypes in usability testing (Kuutti et al., 2001), Virtual Reality (VR) simulation (Tideman et al., 2008; Manninen, 2000; Thalen & Voort, 2012), augmented reality (Woohun & Jun, 2005), and Experience based Virtual Prototyping Simulator (Kumar et al., 2011). However, there is little evidence on how simulation has influenced design practice in relation to user scenarios on UCD in the front-end of innovation.

Other work takes up the challenges of using simulations in relation to design practice and operates between the real and the virtual. Following on from ground breaking earlier studies within architecture on humans and virtuality, Turkle (2010) turned her attention to pitfalls in simulation. She observed that "the virtual makes something seem more real" and that "computer-aided design made theory become more alive" (p. 13), as does Winsberg (2010). In our design cases we found that it is very important to inform the design session participants that the scenarios are mediated representations of "reality".

Previous research in the maritime sector (Grech et al., 2002; XXX & XXX, 2013) has shown the positive implications of carrying out user surveys of complex user-related operations at sea. However, related simulations have not been implemented as part of the front-end conceptualisation phase of design, but at later stages in development. XX and XX (2013) used simulators in front-end development for testing interface ideas.

Game engines

In our research we focus on real-time simulation visualized in real-time rendering (Möller, et al., 2008 p.18) by means of the uptake of game engines. Game engines are a generation of tools that emerged from entertainment rather than industrial and scientific needs, and are used to create games for platforms like *Xbox* and *PlayStation* or personal computers. A core attribute of game engines is aesthetic presentation and efficient production of content. We chose to use game engines to model scenarios and simulate them because for designers they provide a graphical user interface and the framework to model and simulate computer game functions in the same virtual environment without a need for expert knowledge of computer coding.

Game engines like *Unity, Cryengine and Unrealengine* have been taken up as tools in shaping simulations (Kumar et al., 2011). Typical functions in game engines are a 2D or 3D graphics-rendering engine, object collision detection, a physics engine, animation integration, artificial intelligence (AI), sonic integration, scripting and network extensions. All these functionalities can be simulated in parallel to create realistic, world meditating game experiences.

A game engine like *Cryengine* has an editor that has two modes that can be employed when designing scenarios to be simulated. First, the modelling mode uses physics and AI in running the simulation. Second, there is the mode of 'human-in-the-loop' integration or gaming mode in which a user may be involved in the scenario. In our research we mix these two simulation modes.

Research Methods and Design Techniques

We followed two main intersecting qualitative methodological strands: action research and research by design. Action Research is a method that allows immediate research on problems and solutions that is being reflected on in action (Avison, 1997; Hollingsworth, 1997; Miller, 1994). Action research offers a way of studying phenomena in real-life design processes and we applied it as a research method in collaborative design sessions. Archer (1995) argues that, "There are circumstances where the best or only way to shed light on a proposition, a principle, a material, a process or a function is to attempt to construct something, or to enact something, calculated to explore, embody or test it" (p. 11). The processes of action research deal with interactive inquiries where problems are shared collectively and knowledge is produced from action. This means that practice and research can be merged into the same research setting. However, Archer argues that is it is also difficult to generalise from action research because it is dependent on the real world and what took place. Its findings rely of factors such as time, place, people and circumstances.

We tackled this through the generation of three applied cases. Our approach to using action research has been to conduct design projects with industrial partners from the maritime domain. This process consisted of several elements of design briefings, meetings, preparing of design material and collaborative design sessions. The core of action was to exchange information with participants, frame problems, and collect data and user experiences to be used as ground for the construction of scenarios and design concepts. In Case Study One we constructed a ferry scenario that was used in a discursive process of consultative use with the game engine as interface. In Case Study Two we had not pre-planned scenario events. This was done during an explorative design session using the game engine together with the user. In Case Study Three we constructed scenarios of user interactions that were taken up in a design product meeting. This will be elaborated further in the cases below.

In this respect, research by design (XXX and XXX, 2010) is a design practice based inquiry that takes up relations between practice and theory. Central to this have been the pragmatist concepts of reflection-on-action and reflection-in-action (Schön, 1983, 1987). Research *through* design, a mode of making and reflecting, offers a way to not only research reflection-in-action, but to combine this with what is being designed and to simultaneously relate this reflexively to design theory and analysis, in and through participation. This approach allowed us to explore several aspects of the simulation tool and its relations in design practice, and the role and potential of real-time adjustment.

The research drew on a mixture of qualitative methods. The design projects were organised as commercial design ones where design briefs and project goals were defined at the outset so as to design scenarios to be used for concept development. The research on each case was then planned in relation to the project design need and how it might benefit from using simulated scenarios and game engines. A course of design action and collaboration was then planned together with industrial partners. These partners were medium and small sized companies, Lystech and Norwegian Maritime Education (NMU) that supply ship and rig systems, a large state owned concern called Kystverket, and a leading commercial company called Kongsberg Maritime.

Through collaborative design sessions with these various partners we generated ideas and concepts based on the use of simulated scenarios and game engines. The technical process of constructing the scenarios dealt with modelling the context, objects and their behaviours. Scenario events of existing or future situations were then constructed in collaboration with users or the industry partners. This gave us insight into how our approach functioned as a design tool in a commercial setting, knowledge that is needed if we are to understand how to tackle the design challenges described in the Introduction above. The collaborative design sessions were documented using video-recording (Iversen & Buur, 2003). The first author of this article was actively involved modelling scenarios, simulations and facilitated the collaborative design sessions using participatory action research methods (Cahill, 2007). Video-documented sessions were distributed to the participants after such events. Posters of the results and documentation were also created so that the participants had the ability to further use and share them.

During these processes we took up a medley of design techniques: we made design briefs, drew up project plans, organised pre-design mattings, constructed 3D objects, drew 3D context environments, made notes on how to model scenarios settings, planned scenarios using drawing on paper, made physical models of ships, used different types of maps, worked with live data from ship traffic (AIS), sketches from ideas, framed user and design problems and minutes from design workshops. The research data consisted of the design artefacts material made, audio and video recordings, screen captures and research notes from the processes reflecting on how the methods and tools were used. We also drew feedback from users and industrial partners on how they experienced the processes. In Case Study One we compared how a more traditional scenario method using maps and physical objects compared to scenarios using the virtual environment in game engines. Overall, we analysed the material by reflecting on the processes of creating the scenarios, how simulation was to be used and how it changed and elaborated the discursive process of products, systems and users in context for concept development.

Participatory design: stakeholders and collaborative design sessions

To research the relations between design and maritime innovation we developed close connections among various participants in different companies in the sector, as mentioned above Several co-design and participatory design methods were taken up to support such collaboration, such applying participatory design methods and innovation (Dalsgaard & Halskov, 2010) situated in computer systems research (Büscher, et al., 2004), in attention given to materiality (Jacucci & Wagner, 2007), via tangible user interface development (Kim & Maher, 2008), the embedding of expert users (Humphreys, et al., 2008), and moded of collaborative sketching (Johansson, 2006).

In this frame, collaborative design sessions with stakeholders and actors from the companies and a specialist designer (the lead author) working with the dynamic properties of the real-time game engine were adopted. In these sessions and we found that there was a need for more interactive communication in small group design meetings (Olson et al., 1992) often described as collaborative design sessions (Gül & Maher, 2009; Kim & Maher, 2008). This also applied to communication about and uses of 3D simulated representations through which we were able to create more immersed experiences in user scenarios employing game engines. In such sessions designers imagine how products and systems are being used in 'use situations'. This anticipation is a huge challenge because when designing new products and systems we 'design use before use' rather than 'design in use time' (Ehn, 2008). Designing in 'use time' is about being situated in context and the situations of use. The design process becomes immersed into these contexts with a sense of presence. We call this *simulated use time design*.

When combining a simulated behaviour with the concept of real-time, the designer is able to sense and design for a more immersed experience of the simulation scenario and use it to unfold the design process, in a designer's scope and with users in contexts of active use, reflection and review. The core concept in our approach to using computer simulation of user scenarios is to apply behaviours to 3D objects or entities, combinatorially, so they can automatically interact with each other, based on behaviour properties and patterns.

Collaborative design sessions offer potentially productive spaces for drawing together and making use of multiple competencies in designing and in wider iterative and participatory processes of developing scenarios for subsequent use (e.g. Buur & Larsen, 2010). Through several such sessions we worked together with NMU and with Kystverket, discussed ideas and how to shape innovation strategies. Through working with maritime professionals and through co-creation in collaborative design sessions we created views on how the maritime industry might deal with early phase innovation (Jenssen, 2003; Jenssen & Randoy, 2002) and how it may address matters of design complexity and UCD. By using scenarios we were able to connect design places to user and actor participation in collaborative design sessions that drive UCD through tools facilitated by a designer.

We applied different mediation techniques to shape these narrative scenarios (Rosson & Carroll, 2003), such as scale maps and models (Bratteteig & Wagner, 2010), drawing navigation patterns, videos and storytelling (Beckman & Barry, 2009). We experienced that these methods are effective in setting the stage for discussion. We also used problem re-framing techniques (Kruger & Cross, 2006; Lawson & Dorst, 2009; Poulsen & Thøgersen, 2011; Schön, 1983) in collaborative design sessions to create new thinking patterns concerning design processes, conceptualisation and innovation strategies. Our next step was to integrate the game engine with simulated scenarios as means to facilitate collaborative design sessions.

Cases

Case studies are a recognised means and an exploratory approach to social science research concerning contemporary phenomenon within real-life contexts (e.g. Yin, 2009). They are applied in maritime research and inquiry into simulation and user-generated innovation (Buur & Larsen, 2010). To research the potential of the game engine to model scenarios and to simulate actions and behaviours, we drew up three different conceptual design process cases. We applied the game engine to create scenarios based on the design problematic in each case, and looked at different ways of simulating actions and behaviours. The game engine was then used and explored in collaborative design sessions to create collective and shared understanding as well as collective creativity (Sanders & Rim, 2001) through reflection in action and the ability to mediate iterations from co-participants and users in case based inquiry.

Each of the cases addresses a specific need in exploring an individual design space in relation to use and situation. The Oslo fjord case, the first, explores early stage design ideas about an increase in ship traffic to identify problems and arguments to shape new concepts. In the supply vessel case study, the second, a design concept is explored that is based on much more detailed elements and systems in relation to contextual implications. We also tried to actively involve users in the scenario through an avatar to motivate their engagement and immersion. In the third case, a helideck light system, the concept development process was much closer to the end product, and product interaction with users and systems needed to be explored that were based on use in landing situations from a user perspective. While differing, these cases together provided us with a spread of experience in design and contextual responses from a range of participants and users that would allow us to heuristically discuss the application and development of game engines and simulation in early concept phase development.

Crisis Management, Dynamic Positioning and Locational Safety

Case Study 1: Crisis Management in the Oslo Fjord

Crisis management is one of the constant problems in the maritime sector. This case deals with crisis management in the Oslo fjord based on the likely future increase of vessel traffic. A team of actors representing different parts of the industry collaborated with the research team to find new areas for research and development based on present and future risk factors in the fjord. We used the ferry lane between two harbour towns of Horten and Moss as a starting point. The new ferry concession for 2015 noted an anticipated increase of ferry traffic. At the moment the area is the most hazardous coastline in Norway and an increase of traffic might add considerably to existing risks and challenges.

The project team involved researchers, designers, system engineers, captains and product management. Each member offered different knowledge and experience regarding vessel traffic and crisis scenarios. There was a need to create shared understanding on existing navigation and traffic challenges in the fjord. The team needed to be able to apply this knowledge and their own expertise in creating new scenarios that would include increased traffic patterns. Accidents are often triggered by a series of events and it is important to have an overview of the situation before, during and after it being played out. Accordingly, and adopting a holistic approach, we needed to investigate factors before an accident, the accident moment, subsequent search and rescue operation (SAR), as well as considering factors such as how to minimise pollution from oil spills and wider safety processes.

The design challenge was how to create a platform to share knowledge and experience, and where new scenarios and ideas could emerge. Also challenging was how to implement expert knowledge and get expert parties to share their tacit knowledge and experiences. The process and outcomes had to be visualized to overcome some of the design challenges that again created new issues like scale, movement, context, environment factors, interaction, behaviours and accuracy.

The case design brief was based on finding possible risk scenarios in the ship traffic patterns and behaviours. Further, we were to study the navigation challenges based on identified scenarios before, during and after a critical situation had occurred. Here, there is a need to mimic the real world situation of the users. In this case study it was important use actual scale 3D models and program the ship movement according to speed in order to simulate real world conditions. The goal of this choice was to help users recognize the scenario in order relate to their experience in real world situations in order to give valuable feedback on critical situations to be used for product development.

Facilitating the design of an intended system on ships and simultaneously relating to traffic behaviour for several ships required a simulation model that allowed us to chart each of the ship behaviours, such as ship speed and 8 ferries and their crossing the path of a cruise ship and container ship. This represents a typical situation in the area. To observe the ensuing situations, a dynamic view of the situation was needed that could allow one to follow the scenario in motion. It was also necessary that the situation be seen from individual ship bridges so as to be able to explore the navigation challenges on each separate vessel.

The game engine allowed ship speed and course to be simulated. The ship's path and speed needed to be pre-programed. The ships can be placed at desired locations in the virtual environment and the whole scenario visualized in 3D. The terrain was modelled based on real world GIS data and was textured using aerial photos from the area. In order to simulate ships crashing into one other, the 3D objects had to have collision detection. This makes the 3D mesh of an object detect interaction when it comes in contact with other 3D objects.

Through the simulation the ferry traffic was simulated based on the requirements needed to study such situations. However, each scenario that was developed had to be saved individually in separate 'scenes'; it was easy to forget this in the design session when jumping between different scenarios. Because the scenario mimics real world conditions, it can be difficult to see objects that are in the distance. Using the game engine, different selections allowed us to be in an avatar mode, see and the explore the scenario from a user first person view on a ship, and simulation mode, where the scenarios were viewed from any desired angle.

The process: physical modelling and scenarios

In the first collaborative design session we invited professional participants working in the Oslo fjord, including former captains of vessels in the area, vessel traffic operators, pilots, and the XXX. To facilitate the discussion we used physical boat models on top of digital maps and AIS information on a Microsoft SUR40 touch table. The participants accessed the models when explaining existing and possible future events by adding and moving models representing the ships (Figure 1). More ship traffic was added in the scenarios and the discussion continued on regulations and the concern of traffic density in the area.

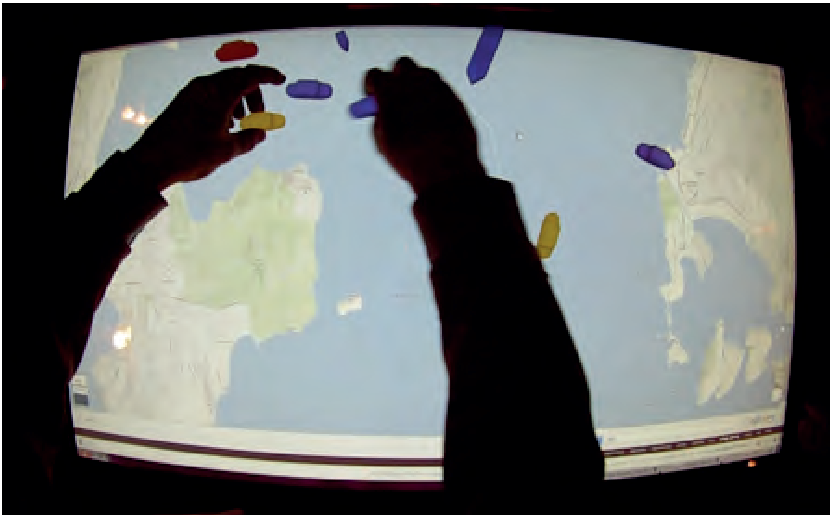

Figure 1. Frame from video showing the pilot moving the ship models.

Prior to the second session, a simulation and visualisation of the scenarios from the first session, using a game engine, were developed by the designer. He acted as a facilitator. The simulation and visualization used the actual scales between the ship models and landscape; the ships had hydrodynamic properties allowing them to be simulated with individual navigation paths. The scenarios evolved in an iterative process where participant feedback was implemented in the simulation and visualisation. At first we simulated eight ferries and the crossing cruise ship and bulk transportation. The traffic pattern triggered discussion about collision scenarios (Figure 2).

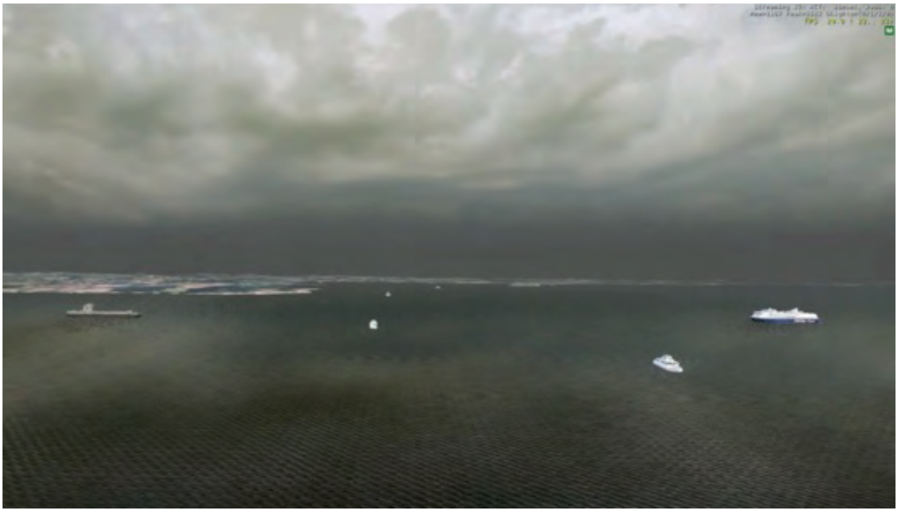

Figure 2. Frame from ship navigation simulation. This part of the simulated scenario shows the ferry and concentration of other ship traffic.

A scenario was devised where one of the ferries had a blackout, a cruise ship had to avoid collision and where there was the potential of hitting a passing bulk carrier. Distance between vessels is deceptive on the ocean but also in apparent range. This is because speed, currents and weather are more forceful than they seem. The scenario was discussed in the group as to what type of factors might lead to such a situation (Figure 3). By changing the surrounding ships' movement we added new factors in the scenario that improved or degraded the situation. The free movement camera option in the 3D tool was used when the simulation was running, and, at the same time, new ships were added or moved to implicate the simulation. In the group, one captain argued that ferries are more likely to end up in dangerous situations or breach regulations because they know they are more manoeuvrable than big cruise ships or bulk ships.

Figure 3. Frame from collaborative design session video that shows the crash scenario being facilitated by the designer closest to the screen.

In the final iteration we created an accident scenario based on the previous collision between the cruise ship and the bulk ship already visualised. At this point we added a rescue helicopter, leisure boats, passengers and crew to materialise how the situation could evolve. This scenario was not iterated in the way previous ones about navigation were. However, this situation stimulated discussion about how the simulation itself could be used to coordinate possible SAR events in a collaborative setting with live data.

A number of different possible risk and accident scenarios were discussed in the collaborative design sessions. New ideas were developed that included the development of automatic docking systems, new collision alarm systems, new pilot training programmes and the need for research about crisis management.

Case findings

There are a number of findings from this case concerning relations between use of tools, collaboration and reflection in and on action:

- the tangible interface had limitations related to scale and visualizing the scenarios from the user perspectives on the ships.
- in using the game engine to facilitate the discussion we were able to create an accurate scale between objects and 'landscape'.
- simulating ship physics and applying AI behaviour made it possible to approximately mimic speeds and movement.
- being able to change perspectives made it possible to facilitate a proposed scenario which often triggered more questions based on the visualization.
- the ability to add or change the scenario during the simulated activity led to the actors

providing more precise inputs on risk factor in the scenarios.

This case provided insights into navigation challenges and seafarers' culture in relation to safety and risk factors in the Oslo fjord. We were motivated to extend this further and were able to do so in relation to offshore activities in contrast to the calmer maritime climate of the fiord.

Case Study 2: Offshore Dynamic Positioning in Icy Conditions

The importance of context

Offshore and deep water maritime operations play a major part of operation and research and development. In the second case study we focused on related design and development maritime research projects at the XXX and at XXX. Both research projects look into decision-making support systems for ship navigation. Oil drilling is starting to move north to latitude 75. Challenges arise concerning technology, operational solutions, safety, logistics, personal equipment, accessibility, equipment quality, rig collaboration, winter preparations and transport (Andersen, 2014), as well as key environmental concerns. This case covers a small collaborative design session with one specialist operator, a Dynamic Positioning Operator (DPO), on a supply vessel concerning operations in the polar areas. The intention was to explore possible scenarios and reflect on a new ship bridge concept. The wider shared project space needed specific feedback on interface and ship design in relation to different operations where ice might be an issue. To explore these offshore scenarios and product solutions there was a need to mimic the icy conditions in the north and to use realistic and accurate models.

The design challenge was to create the design space between specialist maritime user and designer. This is a challenge when dealing with complex structures such as drilling rigs and supply ships. We wanted scenarios to be at the centre of the discussion where the same model could be used if new scenarios or ideas would arise. Creating scenarios for exploration requires 3D models that are detailed enough to allow for such interaction to happen. This includes being able to effect things that you did not expect in the design session plan and scenarios. The simulation allowed us to create a scenario that was not pre-planned; for real world believability, the scenario had to be made and facilitated while the discussion was running.

To explore the supply ship interface design and ship layout, the 3D models needed to be very detailed so as to relate the contextual situation to interface details. Also the contextual object, such as a drilling rig, had to be visualized closely in order mimic real world conditions. The ship had to behave like a real ship in the water in order to mirror its real behaviour if the user was to use the avatar function. She or he also needed to be able to move the avatar around.

In the case study, the game engine had to be able to import 3D objects over a million polygons and simulate buoyancy on water to mimic real world behaviours. Such detail was required to discuss specifics in the design concept in relation to contextual information, such as on the drill rig. To mimic the buoyancy of a supply ship, it had to be possible for physical properties to be added to the design concepts made with different CAD software. The 3D models also needed the same manoeuvring and proportion functions as a real supply ship. This functionality was added to our ship model using an existing action script from the game engine's pre-made assets.

The technicalities of adding complex designed 3D objects from different CAD software functioned very well. However, some adjustment had to be made with the geometry if points were too close or if polygons where twisted. Adding physics to the objects required a trail-and-error process so as to understand the mechanisms that influenced the physical properties. Adding navigational functionalities to the ship concept design was carried out using an existing boat script from the pre-made game engine assets. Propulsion functionality was therefore not functioning as on a real ship, but the user was still able to operate the ship.

Expert programing competence is needed if such functionality is to be modelled. The scenario detail and possibilities of creating scenario situations during workshops worked as a mechanism for driving forward the discussion of the collaborative design session. Usually, new conversations started after finding interest points in existing discussions describing equipment or situations of use in detail, such as when the DPO described how the mariners look for steam from the vent tubes under the ring when starting bulk transfer. If the vent tubes had not been visualised in the 3D model, the topic would probably not have been discussed.

Collaborative design session process: revealing ice related issues

We started the discussion with the DPO on the basics on how he situated the supply vessel in relation to the offshore rig. Our plan was to go through the standard procedures to see where the ship design and ice conditions were potentially critical. The pilot then started to explain how the boat's new radar system worked. This changed the situated knowledge and direction of the imagined development as the new system forced us to engage with the core area of navigation, tools and readability. We moved the editor view to the radar system displayed in the XXX concept (see Figure 4) and the pilot showed how their new radar covered 4 sectors, as opposed to one radar with blind zones, and how that was beneficial because it was possible to get a better overview in areas with ice.

Figure 4. Collaborative design session with offshore supply ship pilot. The pilot explains the radar system concerning positioning of vessel related to rig and ice.

The pilot then noticed the Head-Up Display (HUD) display on the glass of the XXX concept bridge. He said that he was curious how that would work in direct sunlight (Figure 5), and reflected that, "This can be solved with the sun protection film that we use anyway when we have direct sunlight". He then asked if we could make the environment conditions foggier and add night conditions.

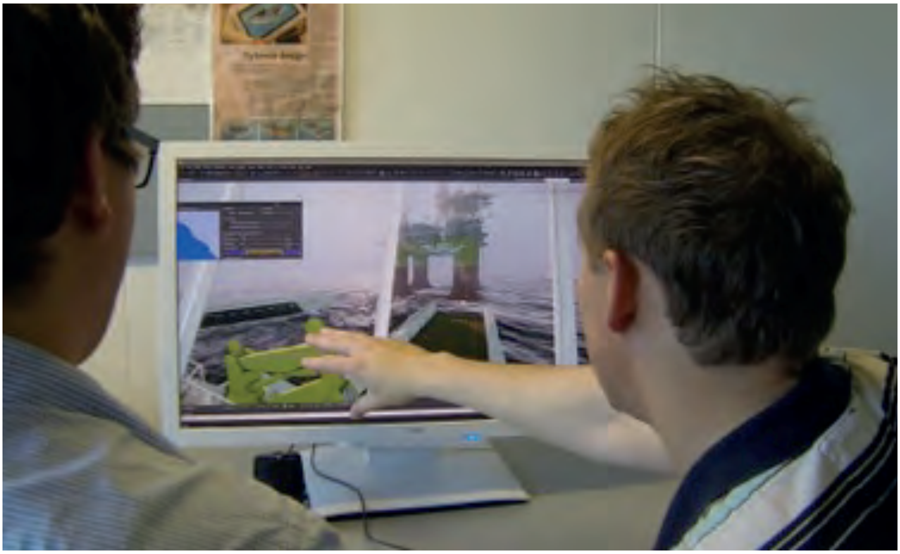

Figure 5. Frame from session video showing how the HUD reacted when changing the sunlight positions.

When adding the fog conditions, the DPO argued that there is a problem with GPS positioning above latitude 75 and that this would be a problem when approaching rigs in conditions with limited vision. He said that they use the radar sometimes within a 500m limit in such foggy conditions, until securing a visual check of the rig. However, some of these procedures might need to be changed in the icy conditions of the far north. The discussion continued about how the DPO would approach the rig with the vessel; the designer changed the scenario according to the DPOs instructions. When moving the camera past the rig rescue boats, a question arose about their relevance. The DPO argued that common procedure is to call the rig to let it know if one is in front of the lifeboats, an area one tries not to be in.

The DPO argued that the wind is a critical element that that is always given close attention. We then added a 10 m/s wind to the scenario and we could see the vessel starting to move toward the rig. The DPO argued that he always tries to have the same heading as the rig and stay on the off drift areas to prevent collision should they lose control of the boat. It is also important to keep an eye on the anchor chains (Figure 6). These various needs and conditions contain complex dynamic components, intersecting technical and knowledge systems and potentially changing seas, and what are often evolving scenarios that may entail partly unpredictable human action.

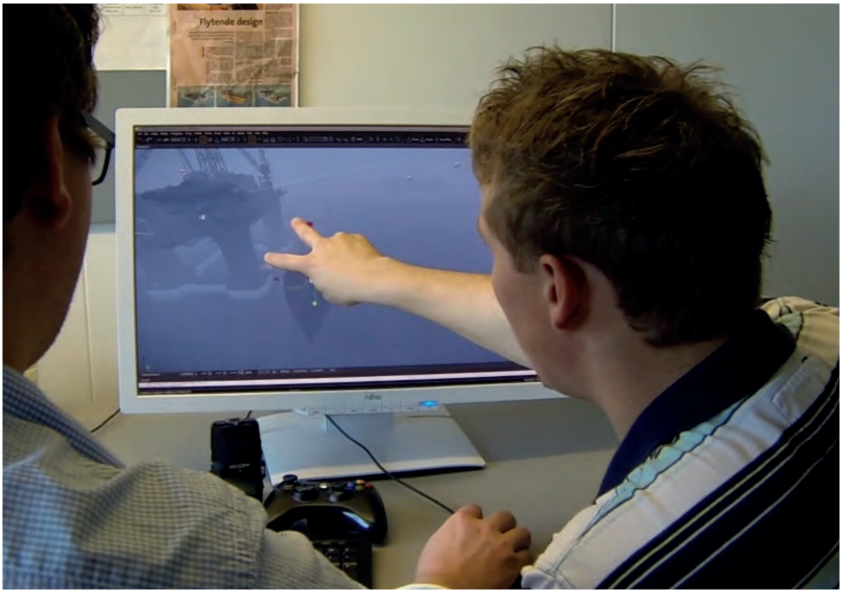

Figure 6. Frame from video showing the DPO describing the anchor chain risk.

When the vessel was then positioned 10 meters from the rig, the DPO asked if we could see the situation from the DP console position. The view was changed accordingly and the DPO argued that the ship chimney was placed in such a position that he would have problems seeing if the rig vent was open if a bulk transfer (water, mud, gas, fuel) was to be effected. We also simulated the crew position when connecting the transfer tubes.

The discussion then continued to the helicopter landing procedures and helicopter ditching rescue operations. A scenario was created with a helicopter in the water and we added a Rigid Inflatable Boat (RIB) as a rescue boat. We then simulated the RIB approach delivering wounded workers back to the supply ship. The DP operator explained how he would protect the RIB from wind and waves on the leeward side of his vessel and that he would use the DP to keep stable and stationary.

We then talked about icebergs as a risk factor and placed an iceberg close to the rig. The DPO argued that icebergs could be plotted in the radar to see if they are on collision course with the rig. If so, we would need to try and change the course of it or try to break it up. If the ice is less then one metre thick, he said they try to break it with the aft section of the ship. We then re-enacted this situation. A new question about icing problems then arose and along with it a need to de-ice; we continued the discussion on how to carry out de-icing of the supply vessel and rig. This may be a new service needed in the polar areas much like airplane de-icing.

In contrast to the measured safety of the simulation environment, at one point the DPO was testing the avatar mode of the game engine and accidentally jumped over board! This led to discussion about ‘man overboard’ procedures, and what the DPO should do if there is a possibility of someone being sucked into the propellers. In these events, the scenarios and user co-designed simulation based responses, and each level of work and related scenarios together presented additional needs and perceptions and indicated considerable scope for further development.

Case findings

Through this case we found that:

- the DPO was able to use the visualization to explain operation and it risk and challenges.
- the designer was able to visualize most of the discussion during the design session. However not all detail could be added in real-time like the bulk tubes or cargo loading.
- a new scenario was created based on the discussion like the helicopter crash.
- some scenarios were simulated using vessel moment (physics), vessel light, and use of RIB in emergency scenarios (‘human-in-the-loop’).
- new challenges and questions came up, based on the visualization and simulation, like the helicopter rescue scenario.
- new discussions arose when the simulation did not go as planned, when the DPO jumped in the water with the avatar.
- real-time manipulations of the sun high could be applied to discuss the HUD display.
- no pre-made calculations had been done on fog density input to view distance; this was a problem when the DPO requested s specific view distance.

Overall, this case found that the game engine provided a means to visualize and model scenarios for offshore operations that expert users could relate to and where they could apply their experience. This method provided insights at a basic operational level, however the DPO thought that this was a good way to focus not only on how they steer the ship but also on issues and factors that create the basis of human decisions. Simulating factors like wind, fog and ice, in combination with small action events provided more in-depth knowledge on special situations.

Case Study 3: Light Systems on Offshore Helidecks

Critical visuals

Safe transportation between land and rigs, and helicopter landing on rigs and taking off from them in deep-sea settings is crucial in the maritime sector. It is also part of the safety of persons, equipment and on-going operations out at sea. This third case dealt with a new light design system for helidecks on semi-submersible drill rigs. The design goal was to simulate the product system in action in a scenario of a helicopter landing. This scenario was developed to explore and reveal design factors that are important in the user interaction with the product.

The light system interface of the product was simulated. This required that the light product had to be triggered by events happening in the scenario. The contextual co-design and user-informed design challenge was to review the proposed light concept with helicopter pilots on the landing and boarding process. Factors like candela values, fog density and view distance were an issue regarding accuracy. We found that there is no mathematical simulation system that can model all the factors in such a simulation and that the users' subjective impression of light will change with age. The light system is currently tested in a lab to meet the required candela specification, however this test does not give an impression as to how the light will behave offshore.

For the system functionality of the helideck light system to be simulated, the 3D models had to be connected to a system that triggered functionality by turning a light on or off. Behaviours from the simulated users (AI) and helicopter landing were the triggering mechanisms of that system. The game engine allows for such programming through the game editor interface. The product system interaction of the helideck functioned and reacted to scenario behaviours. This made it possible to explore and reveal time-based factors related to the product interaction. The scenario and product could be changed during the design session making it possible to explore interaction challenges and possibilities.

The process: helicopter landing

The process started with a meeting with XXX where we agreed on carrying out a small test that visualized and simulated a helicopter approaching the rig at night using the rig's light system (Figure 7). A video of the simulation was developed (and subsequently used in a meeting with the shipyard in Korea) as the first visualization of the system in use. It was then decided to use this simulation and visualization to facilitate a product meeting between the helicopter service and the Lytech company in Norway.

Figure 7. Frame from simulation of helicopter approaching rig helideck at night. The XXX light system is shown by the yellow circle and green "H".

In addition to the view of pilots and to extend our insights prior to talking more with pilots, and to understand passengers' experience and needs, we held a small collaborative design session with an experienced seaman who takes helicopters to work out on the rig. The idea was to obtain extended insight into the experience of landing on the helideck as an expert passenger who has been on numerous visits. Using the game engine as means to facilitate discussion, we went through the different steps of the landing process. This participant argued that it is possible to be confused by all the noise, notably wind, and the blinding lights of the rig. This is especially so for new workers with little experience of the landing and working conditions.

In response, a new gate and living quarter lead light system was visualised and introduced; the user thought this was a good idea. We discussed how the light should look and where it should be placed on railings that are critical to navigating between the helicopter, deck spaces and entry points to interiors of the rig. Our real-time light visualization and simulation presented direct representation on how the system would look; different solutions were developed and discussed with the expert traveller (Figure 8). These solutions included variations of light placement and colours and how this system could be part of a safety video before helicopter take-off prior to going offshore.

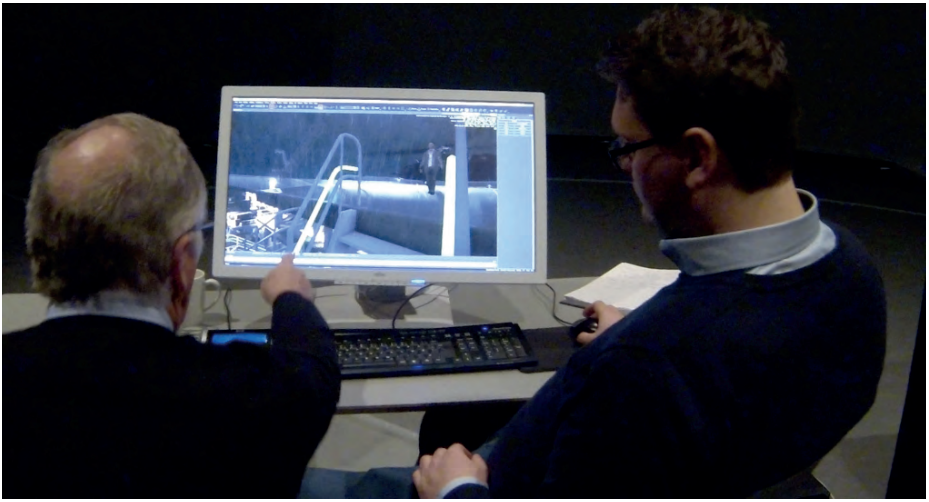

Figure 8. Frame from video. The user explains where the light tubes should be placed on the helideck gate so that traveller-workers can see the steps.

Based on this design session, we developed a scenario implementing different elements of the product. This was to be presented at an existing product meeting in Norway with helicopter pilots (users), suppliers and customers from XXX, XXX, XXX, XXX and XXX. The scenario we demonstrated included a series of different events starting with the helicopter landing, a passenger walking to living quarters and an emergency evacuation event. The same scenario simulation was run in different weather conditions. This is crucial in this professional work setting where climate variation is at times considerable and when weather conditions are extreme.

This intervention via simulated scenarios started discussions on how the light can help a pilot to see his or her altitude in relation to the helideck when approaching. This included deck texture, better visibility concerning fog, ice issues and matters of fuel draining on the helideck in case of a full spill. One of the four helicopter pilots to this session argued that it would have been useful to use the lights to see whether or not the helideck was ready for landing. Our real-time engine allowed us to respond to this and to visualise this suggestion immediately by using red lights around the already demarcated circle shape of the helipad (Figure 9). During the meeting, XXX decided to test the light system on a test-helideck at Sola airport and to submit it to wider user testing.

Figure 9. Screen capture from game engine. The circle lights was change during the user meeting to visualize the helicopter pilot's idea about light colour codes.

Case findings

Through this case we found that:

- by using the game engine to visualize and simulate the light system in user scenarios, participants in the meeting and design sessions were able to understand the system and its function in different situations.
- it was more difficult to create new scenarios during the meeting with 16 participants rather than the small collaborative design session.
- using AI behaviours allowed us to trigger systems that motivated new events. This enabled us to study detailed product functions like if the lead lights should turn on when the helideck gate is opening or after it has open (this was not identified as an issue before the simulation though).
- real time visualization and simulation made it possible for the designer and actors to reflect in action and modify the scenarios to continue the iteration.

Through this case we were able to visualize and simulate the behaviour of a system being designed. When using the game engine in a collaborative design session with actual specialists we were able to discover critical factors and create solutions to meet them together with those specialists. Video capture from the scenarios also provided a visualisation that was used by the engineers at the shipyard to better understand how the complete system will act during operation when it has been installed.

Analysis and discussion

These three cases show how the game engine has been used in different design, scenario and use settings. They also indicate the application of game engines to augment what is typically on offer in looking forwards to meet and anticipate some of the safety and critical needs in the maritime sector. Each case had the basic need to understand processes and saw the value of spaces for collaborative discursive engagement and resulting modifications and new designs and achieved this through co-design activity. We found that the game engine has the capacity to be applied to model user scenarios that occur at sea and that can be simulated in a temporal sequence with object behaviour and interaction.

Abstraction, actualisation, projection

Traditional design practice argues that abstraction should be kept to a level that maintains attention on specific design issues. However, there is little research on trying to make design models incorporate the complexity of contexts of intersecting systems and simultaneous and emergent user needs. In our cases, attention to complexity enabled more exploration that allowed us to address new questions. One example was the lifeboat scenario from Case Two. If we had not integrated the lifeboats into the model, the questions about their relation to the vessel operation would probably not been discussed. The real-time simulation and visualization capabilities of the game engine are the momentum that allows this type of interaction.

The use of real-time simulation of physics and AI brings life and time into our scenarios. Modelling scenarios, with and without a 'human-in-the-loop' and where new events are shaped based on the unknown simulation outputs, drew on the notion of reflection-in-action as part of collaboration and design thinking. However, we do not see these simulations as a test of physics or usability, but as an explorative approach that reveals new factors for exploring and tackling ill-defined and wicked problems. In Case Three, placing the light cable on the railing was thought to be free of serious issues; however, the user informant argued that on ships these rails are often used to fasten ropes! In the simulation space, by changing the position of the light tubes, we discovered that we could light up the deck as well as steps, thereby providing an added safety feature. These immediate responses from the light simulation enabled an iterative reflection-in-action process, leading to the finding of new problem factors and spaces that could together be pursued in order to carry out new solutions that in turn could reveal new meanings.

All types of simulation deal with the issue of accuracy. Because a simulation mimics the real world it can only be measured more or less precisely. Through our cases we found that we can approach these issues from two angles: a) by mathematics and b) via subjective situated user feedback. Using mathematics, to describe a ship's speed, we can measure how fast a ship will complete one nautical mile. When doing the helideck light simulation it was difficult to use a mathematical model because the light experiences are affected by several intersecting conditions and humans' perception of light is different according to age and changing weather properties.

A key element when using simulation via subjective situated user participation is that unexpected events happened. When the DPO was controlling the avatar in the Case Two, he suddenly jumped into the water. This was clearly not something that was planned; however, the avatar AI itself has built in swimming capabilities that allows it to be controlled when in the water! This scenario and the affordances of the tool started a discussion about what to do if you fall overboard and how the DPO should use the thruster controls to prevent the person being sucked into the propellers. Such scenarios may not merely help us to look into actual work and safety matters or indeed experience unexpected ones, but they may also suggest ways to look into a wider, complex and merging set of conditions, people and actions that we cannot always appreciate or see holistically while immersed in safety critical work.

Reflecting on the game engine

Our focus on the game engine has been to investigate what support it allows in tackling design challenges that designers experience in the front-end of innovation. What is needed in this design space is something that allows for reflection-in-action on both an individual and a collective level where designers, actors and users can participate. However, this reflection is also based on modifying the scenarios in an iterative process of reflection-in-action. Each case studies shows that participants were able to apply their knowledge and experiences to the related scenarios in order to modify new iterations of events. This alone does not guarantee collective understanding between designers, actors and users. A discursive process around the simulated environment and operations is therefore needed to support the facilitation in a design group involved in exploratory designing.

The main difference between the use of game engines and traditional scenario development techniques - staged plays sessions (Simsarian, 2003), storytelling (Lerdahl, 2001), exploratory design games (Brandt, 2006, p. 59) experience prototyping (Buchenau & Suri, 2000) and visual storytelling (Buxton, 2007, p. 277) - is the ability to combine several types of media on the same platform and to apply behaviours to objects and systems that can be simulated real time in context. However, there are elements of existing scenario methods that have advantages over game engines, for example the time used to construct the scenario, fine-tuned use situations where it is not possible to ask the AI character itself how it experienced a situation.

The interface of the *CryEngine* tool used in the cases has come a long way in relation to being suitable for adoption by designers with basic knowledge about 3D software and programming. However, many designers are most likely not going to become expert programmers at the level that is needed in order to design code for custom entities. A team of both designer and programmer might be preferable, but again this may make the workflow much more complicated and the tool may lose its qualities as a design tool. Further work is needed into these relations.

The most demanding part of the use of the game engine was to export the 3D objects from *3DstudioMax* to the game engine. There is potential here for the game engine to become a better design tool. When using simulation of scenarios in the case studies we realized that the systems revealed new events that were not planned or expected. In contrast to instigation and exploration where the process is aimed at more analytical approaches, phenomena emerge based on user knowledge that is integrated during the collaborative design sessions or outcomes of simulated events or behaviours.

Another question is what a simulation constitutes in the sense of a scenario. It is possible to view the simulation on two levels. One is the traditional mathematical system approach that is calculated based on formulas. For example, this is the physics system and the light system in the game engine. The other level of simulation is the behaviour of AI characters and objects. There is a thin border between visualization and simulation here. In a scenario simulation the relation between behaviour, action and time is critical.

Interesting aspects that arise with scenario-centred computational simulation include the possibility to investigate, experiment, reveal and explore very complex situations and activities. An example of this is crowd simulation where AI characters behave on the basis of interaction between each other and the environment. This is often used in movies when animating thousands of characters simultaneously. There is then an issue of complexity. The ability to design for systems and users in context of high complexity might be the reason why the involvement of designers and UCD process are used only to a limited degree in the maritime industry. There is room for this to be extended in future research.

Two examples show how issues of perceived complexity outweighing situated knowledge may be countered via design, centred on and realised through exploration, with game engines and simulation. First, when we used the physical artifacts in our first collaborative design session with the XXX when discussing crisis management in the Oslo fjord, at one point in the design session one of the pilots said, “There is a collision alarm on the cruise bridge that is automatically turned off when approaching this area.” The event described was of huge interest for further investigation, but the physical models did not allow us to go inside the cruise bridge to investigate the alarm system. This gave us the idea of bringing in full-scale bridge simulators in these collaborative design sessions to look at specific interface and navigation issues.

Second, when using the game engine to facilitate the discussion of supply ships in Case Two, the ability to instantly change the perspective view based on discussion input took the discursive process into a new dimension where relativity of scale could be presented and achieved. However, it is critical that a designer who has expert knowledge of the tool is the one facilitating the tool-meditational process, while responding to insights and direction from the expert user/s. It is a considerable challenge to use the game engine interface in interacting with and modifying the scenarios. These case based examples should not be seen to suggest that this is a simple process or activity but they reveal considerable potential for further inquiry.

Conclusions

We have presented several aspects regarding the use of computers to model and simulate user scenarios when designing complex systems in the maritime sector. We have carried out an exploratory design research strategy to find new design methods to handle complex systems and behaviours in UCD with the real-time capacities of game engines at the centre. We studied: 1) how computer simulated user scenarios may be used as means to facilitate a design process to explore and reveal possible design solutions and problems in the maritime sector, and 2) how *a game engine* may be used as a design tool in user scenario development to facilitate design for complex systems and contexts. These questions were explored through three case studies of collaborative design sessions that had different design perspectives concerning design outcome, collaboration challenges, design process stage and user involvement needs. Design centred collaborative sessions were analysed to see how to model the scenarios and if the simulation supported scenarios could function as embodied in the collaborative design sessions.

In answer to the first question above, simulated scenarios provide a very powerful means to approach maritime design complexity because they provide a systematic connection of interaction between users, system and operational factors. Traditional UCD scenario techniques lack the ability to handle complexity issues typical in maritime contexts and to efficiently visualise them. Examples of this occur in micro and macro operational levels of user interaction and overall operational implications. Several systems might need to be engaged to see how they influence a situation in a wider perspective. This requires time-based design tools that can materialise a situation and make it accessible to be modelled and analysed by designers. Different simulation techniques offer the possibility of mimicking real world physics conditions that enable designers to model contextual boundary conditions. By simulating trigger mechanisms and behaviours in time-base scenarios it is possible to construct user situations that interact with the contextual conditions. The result of this is that design processes may become more immersed into ‘design in use time’ related to context.

Second, game engines as design tools can be used to model user scenarios in respect to complex systems; they facilitate the possibility for multiple behaviours to be simulated at the same time. This method enables the designer to shape scenarios with great complexity. These scenarios can be used to foster reflection-in-action on the part of designers, actors and users. By using real-time visualization technology in combination with pre-made AI models and physics scripts applied to designed 3D objects, it is possible to create simulation of instances of users interacting with systems and adjusting them ‘en route’. These approaches offer designers a totally new role in development were scenarios are critical in order to understand relations between users, systems and operation in the maritime sector. Consequently, the designer (or design team) has a central and important role in design sessions in linking the scenario, tool and methods. It is the designer who connects the design elements of systems, operations, technology user interactions, and combines them in relation to context and situations. This applies not only for UCD related design issues, but also technical engineering related problems. We believe that this orientation of the designer and team may also likely result in a more user-focused design processes than generally appears in maritime design. This might help to reduce human failure as a main cause of accidents.

Earlier research has found that tools like game engines require expert knowledge, typically from HCI. However, recent trends from other domains of interaction design and industry contexts of use show that designers are adopting game engines and coding to design interactive games, interfaces and systems. We have shown how a designer is able to use knowledge and skills from CAD applications when approaching the game engine as a design tool. The results indicate that user scenarios can be modelled and simulated without first hand expert knowledge about computer coding. It is the intuitive editor interfaces in the game engine that allow for an effective and communicative workflow to be achieved and conveyed to others in dynamic and dialogical settings of work and need. Naturally there is room for further access to expert coders and for teams that include a mix of designers and programmers.

In our cases, scenario input was modelled by way of a discursive process together with specialists and users. The real-time technology allowed us to change the simulation model when the simulation was running. The immersive capabilities of the real-time technology created a fast workflow in an iterative process where the game engine could be used as part of a design session setting. When decisions on concepts had to be made, the simulated scenarios were used to create shared understanding between the designer, actors and users.

We see that in the conceptual phases of design there is a need to create a more convergent perspective on use situation in relation to design of products, interactions and systems and that simulations using game engines can assist in this. The users in Case Two expressed this during their design session with us. The dynamic process operator user has hundreds of hours of simulator experience. It was because we used a designer to facilitate the model and simulation interaction that the user did not need to focus on the navigation and handling of the offshore supply-ship; instead, he could focus on the overall operation.

Similarly, the collaborative design sessions developed into a form of revelation in and through the processes of intersection between the content and expert knowledge, the capacities of the tool and the dialogue between participants, all based on scenario modelling and simulation. When we explored and tested scenarios, new events or needs emerged that needed attention and that again could be modelled and simulated. Concerning the design tool properties of the game engine, the free camera views enabled unhindered navigation through the scenarios by allowing a person and a team of persons to look at different aspects or options and focusing on micro and macro levels of an activity or event. Being able to change mode view had huge advantages when facilitating the design sessions. It gave the scenario a better flow between the factors involved in the details in the design and how the design related to the overall operation scenario.

Our overall conclusion is that using game engine and simulation has allowed us to explore situation and settings in front end stages of design processes where we could investigate ideation and mediate them through a tool, with users and relation to complex use for the maritime sector. We also see advantages of using game engines as design tools and materials beyond the maritime sector in contexts of similar complexity. The design oriented collaborative and participative uptake of game engines in scenarios of use may have wider application in other knowledge and design domains where simulation may be taken up in the early conceptual phases of designing. In this respect there is further room for design-driven innovation to add insights to the current body of research on and through simulation.

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To be added subsequently

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