Visualization and Simulation Technology in Healthcare - From a technology-centered to a human-centered perspective

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Visualization and simulation technology in healthcare

From a technology-centered to a human-centered perspective

Johanna Persson

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With the aid of modern computer technology the application of visualization and simulation technology has become increasingly important in today's society. Through computer modelling it is possible to experience, understand and explore environments, systems or objects in two or three dimensions and to see, hear and sometimes tangibly feel them. It may be environments or objects that do not yet exist, that are to be changed or for some reason are not possible to interact with or evaluate in the real-life setting. Many areas of application have been found for visualization and simulation technology over the years. Examples are systems for training in various settings or for simplifying and sharing complex information. But the technology can also be used as a method in design and planning processes as a mediating tool for concretizing ideas or transforming stakeholders into active participants.
Healthcare is one context in which visualization and simulation technology has been adopted for certain tasks but has the potential to contribute to many more. Healthcare is characterized by continuous changes related to work organization, facility planning, treatment routines, and use of technical equipment, in order to improve care and make it more resource efficient. This requires new ways of thinking about how resources are to be allocated when planning new healthcare organizations or changing existing ones. As part of this process I suggest that visualization and simulation technology can be used to train generic and specific skills, plan new organizations and involve staff and patients in the design and development. The first aim of the research presented in this thesis is thus to increase the knowledge about how visualization and simulation technology can be used as a method for sharing information and knowledge and to support training, planning and participation in the healthcare context. In so doing, the results can contribute to an improved work environment for the staff and safety for both patients and staff. Three empirical cases were examined, two of which relate to training applications and one to planning. Participation is touched upon in all of them but has had a more central role in the latter two.
When it comes to the development of visualization or simulation systems, much of the research has had a technology-centered perspective, often focused on more advanced graphical representations and new ways of interacting. Less focus has been put on the actual use situation around these systems. In this thesis I argue that a human-centered perspective can help to ensure that the users' needs, tasks and contexts are guiding the design and development processes. The second aim has thus been to put forward a discussion about a technology-centered versus a human-centered approach in the design and development process of visualization and simulation technology. This discussion has grown out of the different methodologies adopted in the three case studies.</td></tr>
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Contents

Abstract

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When it comes to the development of visualization or simulation systems, much of the research has had a technology-centered perspective, often focused on more advanced graphical representations and new ways of interacting. Less focus has been put on the actual use situation around these systems. In this thesis I argue that a human-centered perspective can help to ensure that the users' needs, tasks and contexts are guiding the design and development processes. The second aim has thus been to put forward a discussion about a technology-centered versus a human-centered approach in the

design and development process of visualization and simulation technology. This discussion has grown out of the different methodologies adopted in the three case studies.

The research has been guided by methods and principles from human factors and human computer interaction with data gathered through observations, interviews, questionnaires and video recordings. This means that the results are based on both subjective data from the participants in which they have expressed their thoughts about the visualization and simulation that has been applied, and on objective data in which the participants' reactions have been assessed by analyzing video or observing the participants directly in the context.

The results show that visualization and simulation technology can contribute to information and knowledge sharing as well as support training, planning and participation in the healthcare context. Case 1 is a typical example of how the development of these systems is carried out today – with a technology-centered perspective. The case involves an expansion of an existing system so that it can be used for the training of a wider range of patient cases and for planning specific surgical procedures. Case 2 however shows that when adding a human-centered perspective to the development process by involving users in design and focusing on their needs, tasks and context, new applications and new ways of designing the technology may be found. Case 3 is an example of how a range of visualization and simulation technologies can be combined to involve staff in a development process to elicit their knowledge of the work organization that can contribute to the planning process.

The results also show that a human-centered approach is employed to some extent in a small part of the simulation training community, while a more comprehensive implementation of this way of thinking falls short. One of the obstacles to a more frequent and easy employment of visualization and simulation technologies in general is that the method still "belongs to" the technical community and in order to use it, someone with technical expertise has to be part of the process. If human-centered perspectives becomes a natural part of the development and application of visualization and simulation technology, a better balance can be achieved between the technology-centered focus of creating high-tech and advanced solutions and the human-centered focus, where the needs, tasks and context of the users guide the development.

Svensk sammanfattning

I ett väderälskande land som Sverige finns det väl ingen som inte är bekant med den väderkarta som ger oss information om hur prognosen för den närmaste tiden ser ut? Många av oss tittar dagligen på väderrapporten och låter den hjälpa oss att bestämma om vi ska cykla eller ta bussen, sätta på grillen eller laga mat i ugnen. Genom enkla visualiseringar i form av sol, regn och moln kan vi alla ta till oss information som i grunden är oerhört komplex och baserad på avancerade matematiska datasimuleringar. Väderkartan är ett exempel på hur visualiserings- och simuleringsteknik kan användas för att förmedla komplex eller abstrakt information på ett sätt som var och en kan ta till sig.

Denna avhandling handlar om hur just visualiserings- och simuleringsteknik kan användas inom sjukvården som ett verktyg för utbildning, planering och ökad delaktighet. Sjukvården är en intressant miljö då den ständigt genomgår förändringar på olika nivå och står inför stora utmaningar i och med en växande äldre befolkning och en ökad andel människor som lever med allvarliga sjukdomar. Visualiserings- och simuleringsteknik kan vara ett hjälpmedel i förändrings- och effektiviseringsprocesser i denna miljö genom att bidra med nya sätt att fortbilda personal och sprida information, samt som ett hjälpmedel att planera framtida förändringar på ett hållbart och resurseffektivt sätt. Avhandlingen har två övergripande forskningsmål. Det första är att öka kunskapen om hur visualiserings- och simuleringsteknik kan användas inom sjukvården för utbildning, planering och ökad delaktighet. Det andra är att lägga grunden för en diskussion om hur fokus i utvecklingen av visualiserings- och simuleringsteknik kan skiftas från det nu rådande teknikperspektivet till ett fokus som sätter användarnas behov, uppgifter och kontext i centrum för vilken teknik som utvecklas och tillämpas.

Avhandlingen bygger på tre empiriska fall där visualiserings- och simuleringsteknik applicerats inom sjukvården. Fall 1 beskriver en simulator för höftledsoperationer som använder sig av virtuella patient-modeller och haptik för att efterlikna den verkliga situationen vid ingreppet för en höftledsfraktur. Fall 2 är en annan form av simulator som ger exempel på hur tekniken kan användas i andra sammanhang än kirurgi. Här undersöks hur man genom datorbaserade scenarion kan träna på att använda och tolka informationen från medicinteknisk utrustning för en viss typ av intensivvårdspatienter. Till skillnad från fall 1 så har processen för design och utveckling i fall 2 varit styrd av användarnas behov och kontext. Fall 3 beskriver hur visualiserings- och simuleringsteknik kan användas som hjälpmedel i en planeringsprocess. I detta fall skall en barnakut planera nya lokaler och ny organisation och som en del av den processen används visualiserings- och simuleringsteknik för att delge information, utvärdera olika förslag och göra personalen till aktiva partners i processen.

Som ett resultat av avhandlingsarbetet, med resan från den initiala mer teknikdrivna studien i fall 1 mot de mer människo- och behovs-centrerade studierna i fall 2 och 3, har en reflektion kring teknikperspektiv kontra användarperspektiv växt fram. Resultatet av detta är, förutom en fördjupad diskussion på temat, en översiktsartikel om hur dessa perspektiv behandlas i utvecklingen av visualiserings- och simuleringsbaserade verktyg för utbildning inom sjukvården.

Genom ovanstående studier och diskussionen i kappan bidrar denna avhandling till att öka kunskapen om hur visualiserings- och simuleringsteknik kan användas för nya sätt att lära och arbeta i förändringsprocesser i sjukvården, samt för att ge ökad delaktighet i utvecklingen av verksamheten. Vidare understryker avhandlingen hur ett större fokus på användarnas behov, uppgifter och kontext i utvecklingen av tekniken behövs för att säkerställa att tekniken appliceras där den bäst behövs och på det sätt som den bäst kommer till sin rätt.

Acknowledgements

The journey towards this thesis started already in 2003 as a doctoral student at Linköping University. After completing a licentiate degree in 2006, I was sure that the life of a researcher was not for me. I told my husband that if I ever considered becoming a doctoral student again he would remind me about that feeling. In 2011 that moment appeared. We had moved to Lund and I was looking for a new workplace. The Division of Ergonomics and Aerosol Technology (EAT) presented an interesting environment where the use of technology was studied from a human-centered perspective. I was offered a job in a project that focused on the use of visualization technology for learning, participation, planning and change in healthcare. Today I am glad that I did not listen to that old feeling. The multidisciplinary environment at EAT has at times been challenging and hard to comprehend, but it has always been very stimulating and engaging to work in. Due to the length of my journey, many people have been involved who deserve to be acknowledged.

My interest for the use of visualization and simulation technology in healthcare started at the master's level when Professor Anders Ynnerman introduced me to the field of visualization in an engaging way. He also made it possible for me and a friend to perform our master's thesis studies at a research center in Italy, working on a visualization-based application for hip surgery planning.

This interest developed further during my time as a doctoral student at the Department of Biomedical Engineering in Linköping. I would like to thank my colleagues there for the opportunity to participate in their research, for their support and for many exciting conference trips around the world.

During my time here at EAT I have had the privilege to meet many interesting and nice people. This has contributed to a friendly atmosphere and enjoyable coffee breaks. Among all these people, there are a few in particular that I want to thank. They include:

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All the participants in the research studies that have contributed with their time, interest and experience and thereby helped to form the content of this thesis. Especially the eminent ladies from the Children's Emergency Clinic at Kristianstad Hospital and the Infectious Diseases Clinic at Skånes University Hospital in Malmö. You made the research both relevant and fun and I learned a lot during our work together!

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Appended papers

This thesis is based on the following scientific papers, which will be referred to in the text by their numbers. Papers Ia and Ib refer to empirical case 1, Paper II to empirical case 2, and Paper III to empirical case 3. Paper IV is a literature review. The papers are appended.

Paper Ia

A Hip Surgery Simulator Based on Patient Specific Models Generated by Automatic Segmentation

J. Pettersson (author's birth name), H. Knutsson, P. Nordqvist and M. Borga. Medicine Meets Virtual Reality 14 (MMVR), *Studies in Health Technology and Informatics*, 119, 431-436 (2006).

A mathematical algorithm for automatic segmentation of the hip bone from computed tomography data was developed. I performed the development related to the automatic segmentation, with contributions from Knutsson and Borga regarding the algorithm development and Nordqvist regarding the simulation system. I wrote the paper with contributions from the co-authors.

Paper Ib

Simulation of Patient Specific Cervical Hip Fracture Surgery with a Volume Haptic Interface

J. Pettersson (author's birth name), K. Palmerius, O. Wahlström, B. Tillander and M. Borga. *IEEE Transactions on Biomedical Engineering*, 55(4), 1255-1265 (2008).

The simulator system from paper Ia was further developed to handle fractured bones, and the haptic and visual feedback was improved. I developed the automatic segmentation so that it could handle the fractured bones, with contributions from Borga. Palmerius changed the haptic and visual feedback, while Wahlström and Tillander supported with their expertise in the field of hip surgery. I wrote the paper with Palmerius, with contributions from the other co-authors.

Paper II

Evaluating Interactive Computer-based Scenarios Designed for Learning Medical Technology

J. Persson, E. Dalholm Hornyánszky, M. Wallergård and G. Johansson. *Nurse Education in Practice*, 14(6), 579-585 (2014).

A simulator prototype for learning to handle medical technology in the context of critical care was designed in a participatory design process. I designed the study with the co-authors, worked in the design process, developed the prototype, performed the evaluation and wrote the paper with contributions from the co-authors.

Paper III

Informing Hospital Change Processes Using Visualization and Simulation Tools

J. Persson, E. Dalholm Hornyánszky and G. Johansson. *Health Environments Research and Design Journal*, 8(1), 45-66 (2014).

A combination of visualization and simulation technologies were used in a planning process of new facilities and a new organization for a children's emergency clinic. I designed and performed the study with the co-authors, analyzed the material and wrote the paper with contributions from the co-authors.

Paper IV

Simulation in Healthcare – From Technology-centered to Human-centered Design and Development

J. Persson. *Submitted for publication* (2015).

This paper is a reflection on the technology-centered versus human-centered perspectives in the design and development processes of simulator systems for training in healthcare. It consists of a literature review that studies the extent to which a human-centered perspective is present in this process. I performed the review and wrote the paper.

Introduction

This chapter introduces the content of the thesis by presenting background to the research area and the healthcare context in which the empirical studies took place. I then present the aims of the research and my research journey. I describe the research projects that served as the basis for the research and conclude with the disposition of the thesis.

For most of us, the weather forecast is probably the most well-known application of visualization and simulation technology (Fig. 1, top left). It presents a simulated scenario of what the weather will be like in the near future by means of a relatively simple visualization using objects such as suns, clouds and raindrops to illustrate the simulated data. When we watch the weather forecast there are not many of us who think about the complexity of the underlying calculations and the work needed to transform this information into an easily accessible representation. This is a good example of how visualization and simulation technology can be used to share complex information with others who do not know and do not need to know anything about the underlying process. There are many other applications in which visualization and simulation technology offers a powerful way to present information and provide insight into matters that would otherwise be unavailable to the consumer of the information. These applications can be used for healthcare training (Fig. 1, top right), for the planning of cities or buildings (Fig. 1, bottom left), for making complex information accessible (such as the web-based information visualization tool *Gapminder*) (Fig. 1, bottom right), for education in schools, and for production planning in industry, to name a few.

With the aid of modern computer technology the application of visualization and simulation technology has become increasingly important in today's society. Through computer modelling it is possible to experience, understand and explore environments, systems or objects in two or three dimensions and to see, hear and sometimes tangibly feel them. It may be environments or objects that do not yet exist, that are to be changed or for some reason are not possible to interact with or evaluate in the real-life setting. In these environments the users are not just passive observers. They can move around, interact and test various functions in order to discover what works well or not.

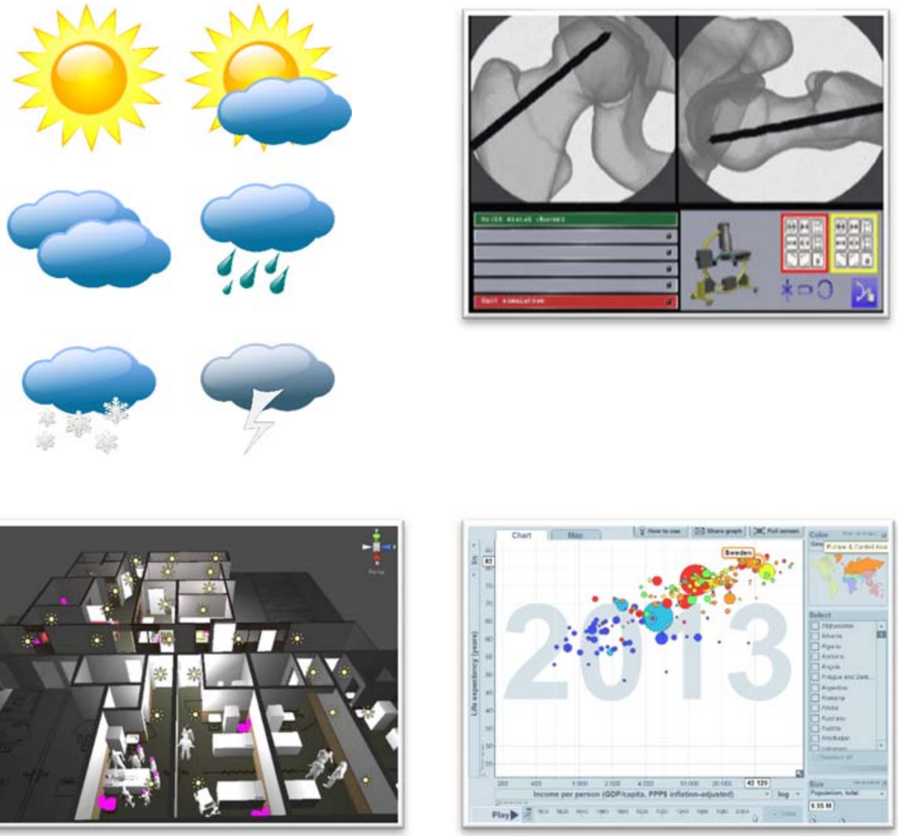

Figure 1. Examples of how visualization and simulation technology is used in various applications: weather (top left), healthcare training (top right), facility planning (bottom left), and information visualization such as the one provided by *Gapminder (Gapminder, 2015)* (bottom right).

This increased used of advanced visualization and simulation technology is due in part to increased access to inexpensive hardware and software with high capacities. This means that the cost of the technology is no longer unreasonably high and not only available in specialized laboratories. Visualization and simulation technology can thus be used in a variety of applications and the technology itself is no longer the bottleneck. This development is even further stimulated by the fact that today, almost everyone carries around a small computer in their pocket – a smartphone – where multitudes of data may be accessed and used for various purposes.

Although there are numerous applications available, there are still many settings and activities where this way of approaching a problem or presenting information can provide more support. What needs to be done is to evaluate ways to practically implement the use of these technologies in potential settings and activities (e.g., in change processes, for education and for information sharing) in order to understand how they can be an aid. So far, technical development has been the primary driving force for many of the applications. Computer games are sometimes so realistically rendered that they are mistaken for real footage; a new facility is presented by means of a beautifully visualized environment with a high level of both interior and exterior details; and medical training offers high-fidelity simulations involving physically advanced mannequins and anatomically precise digital models of a patient. But is such high fidelity always needed? Information can be presented in other forms to encourage user involvement or increase learning; and other areas of application are out there still yet to be found in which visualization and simulation technology can be a useful tool. This thesis emphasizes the *application* of visualization and simulation technology in ways that can best support the needs of humans or organizations, rather than focusing on its technical development. From my perspective, this means promoting human-centered methods, emanating from human factors and human-computer interaction, in the design and usage of visualization and simulation technology based on an explicit understanding of users, tasks and environments.

The healthcare context

The context for the studies in this thesis is healthcare. Visualization and simulation technology has been used in applications for training, planning and participation in various hospital clinics (intensive care, infection care, emergency care, surgery) and involving different professions (doctors, nurses and assistant nurses).

Healthcare has always been and will continue to be an organization exposed to changes induced by society, politics or internal edicts. Much of current healthcare is focused on the challenges of a growing proportion of elderly citizens and patients with multiple diseases. Simultaneously, the demands for increased quality, efficiency and safety are trying to be met. Areas that have gained much attention are the introduction of e-health solutions, the continuous progress of technological and medical innovations, and the development of future and more decentralized healthcare facilities for providing future care (Future Hospital Commision, 2013; Rechel, Wright, Edwards, Dowdeswell, & McKee, 2009; Sveriges kommuner och landsting, 2005). This is why healthcare is an interesting and dynamic context in which the exploration of ideas and methods for new ways of working is important.

New technological interventions and the increased use of computers, smartphones, etc., in both professional and private life open the door for the exploration of alternative ways of providing educational experiences by means of technological aids. New forms for training and education to engage professionals in their continuous education must be explored. This is further strengthened by indications that the opportunities for bedside training alongside an experienced practitioner are decreasing (Qureshi & Maxwell, 2012).

When it comes to planning, the importance of efficient and participatory processes that involve the public, healthcare workers and other stakeholders has been acknowledged (Rechel et al., 2009), at least concerning larger projects such as planning a new hospital. But healthcare deals with continuous change processes on all levels in the organization, involving for example merging units, moving to new facilities within a hospital, or changing the work routines in a given unit. Practitioners have expert knowledge about their work context and are important partners in these processes. Using participatory methods in which the practitioners' knowledge is accessed and applied is hence preferable, whether it concerns planning processes or the development of new tools for training. Participation is further motivated by the fact that the healthcare sector is an environment characterized by strong professional identities with a high degree of specialized knowledge. Involving these professionals and letting them contribute as experts will increase the likelihood of gaining acceptance for a change, while simultaneously decreasing the risk of introducing solutions that do not function well in practice.

The understanding of healthcare as an environment that is continuously exposed to change, that is highly reliant on communication between people, and where an acceptance for changes must be gained for them to be realized, suggests that it is of utmost importance that the implementation methods need to be efficiently integrated in the organization. It is also of utmost importance that this is done without decreasing patient safety or worsening work environment conditions. This indicates that the competence of the people in the organization and their needs should guide the process. This makes the healthcare context an interesting setting for studying the application of visualization and simulation technology as a method for training, planning and participation for a sustainable and healthy working life and organization improvement.

Research aims

The following research aims frame the content of this thesis:

Research aim 1: To increase the knowledge about using visualization and simulation technology for training, planning and participation in the healthcare context. This was realized by examining three practical cases of which two relate to training applications and one to planning. The aspects of participation (i.e., the involvement of users in a process) and how the technology can support this is touched upon in all of them, with a more central role in the last two. Case 1 (Papers Ia and Ib) presents a virtual reality-based system for hip surgery training and methods to evolve this generic training tool into a patient specific tool that can also be used for surgical planning. Case 2 (Paper II) is about the participatory design process of an interactive computer-screen based simulator for training the use of medical technology in critical care. Case 3 (Paper III) focuses on the use of visualization and simulation technology as a method for informing a planning process in which the practitioners are active participants in its design and development.

Research aim 2: To put forward a discussion about a technology-centered versus a human-centered approach in the design and development process of visualization and simulation technology. The discussion is based on the results of moving from a more technology-centered process in case 1 to a more human-centered process in cases 2 and 3. In addition, a review of the use of human-centered methodology in the design and development of training systems in healthcare is presented in Paper IV.

My research journey from licentiate to doctorate: from a technology-centered to a human-centered perspective

To fully understand the content of this thesis, I will start a few years back in another setting where my research journey began with doctoral studies for a licentiate degree.

Automatic Generation of Patient Specific Models for Hip Surgery Simulation (Pettersson, 2006) is the title of my licentiate thesis, presented at the Department of Biomedical Engineering, Linköping University in collaboration with the Center for Medical Image Science and Visualization, Linköping University Hospital in April 2006. In this research I developed medical image processing algorithms applied in the context of surgery simulation. My focus was on the process of generating the virtual bone models for a hip surgery simulator and how these models could be automatically generated from real patient computer tomography data. The application itself – the surgery simulation – was a technically advanced device provided by Melerit Medical AB, utilizing virtual reality technology with haptic[1] technology for tactile feedback and realistic computer graphics for visual feedback. My licentiate thesis provides an insight into the algorithms behind the medical data processing as well as the application of these models in the simulator used for surgery training. This research is presented in case 1 in this thesis.

The bridge between my licentiate degree and my current doctoral studies stretches across some years of work as an application engineer in a private company that developed image processing cameras for automation industry. In this role, I came in contact with many users of the company's products. These users struggled with product

[1] Haptics refers to the ability to feel virtual objects through a special computer interface that produces tactile feedback.

interfaces that were only developed for someone who knew how the product worked "under the hood" and were not easy to manage if you were not well trained in using the product. My time at this company made me think about the user perspective and got me interested in how products and interfaces could be better adjusted to the people who were going to use them.

Working at the Department of Design Sciences and the Division of Ergonomics and Aerosol Technology has given me the opportunity to develop my knowledge about the interaction between humans, technology and work. The Department focuses on how people interact with, influence and are influenced by their environment. This includes technological systems, other people with whom we cooperate, and our physical surroundings. The research findings are used in the design of products and environments that people come in contact with in their daily lives in the workplace, at home and in the community.

This thesis summarizes my journey by bridging the change from a primarily technology-centered perspective to a more human-centered one in my experiences. It shows the shift I made to focusing on the application of the technology rather than on its technical development, and paving the way forward to new projects in the field of interaction between people, technology and design.

Research projects

The basis for the earlier research performed during my licentiate studies (case 1) is a project about the automatic generation of patient specific models for hip surgery simulation. The goal was to develop a method that could be used to integrate models obtained from real patient data into an existing surgery simulator system. This project was a collaboration between Linköping University, local healthcare services and the Melerit Medical AB Company. Papers Ia and Ib present two iterations in the development of this process. The project was sponsored by the Swedish Agency for Innovation Systems (Vinnova) and the Swedish Foundation for Strategic Research (Stiftelsen för strategisk forskning) and lasted for three years.

The more recent research presented in this thesis (case 2 and case 3) has been carried out in a research project called *Computer-aided Visualization for Learning, Participation, Planning and Change in Advanced Healthcare* (Datorstödd visualisering för lärande, delaktighet, planering och förändring inom avancerad sjukvård) with the overall objective of developing and applying visualization and simulation technology in healthcare environments to generate general knowledge of how visualization and simulation technology can be used as a tool for improving safety and efficiency in these work environments.

The project had a participatory research approach in which researchers and practitioners from advanced healthcare worked together to find suitable applications for visualization and simulation technology, based on problems or issues in their work environment. Two clinics from different hospitals participated: an infectious diseases clinic and a children's emergency clinic. The results from each case relating to the two clinics are presented in Papers II and III, respectively. The project was sponsored by AFA Insurance and lasted three years.

Thesis disposition

This is a compilation thesis consisting of a comprehensive summary and a set of five appended papers. This introductory chapter is followed by chapters that present the theoretical context, the research design, methods and data analysis, a summary of the papers, a discussion including implications for practice, conclusions and ideas for further research. Of the five appended papers, four are reprinted with permission from the proceedings and journals in which they were published and one has been submitted for publication.

Theoretical context

This chapter presents the theoretical context that has served as a basis for my thesis research. It provides the reader with the "glasses" through which to view the research. First, the concepts of visualization and simulation and their applications are presented. This is followed by a description of the fields of human factors and human-computer interaction, and the intersection between these fields in which my research is situated. The human-centered perspective is elaborated upon and the chapter concludes with a presentation of how methods from design research have been used to elicit and share knowledge in the studies presented.

Visualization and simulation technology

Visualization and simulation are related concepts and are sometimes used intertwined. Visualization is about making information and data graspable by presenting it in ways that are relevant for the task by means of visual elements, such as diagrams, graphs, sketches, three dimensional models, and physical prototypes. Even though the word "visualization" is used, this technology also includes computer generated input to other senses, such as audial and tactile input.

Simulation is about using available knowledge to replicate scenarios that might occur or are likely to occur, and thereby prepare for future situations. The two terms overlap since a simulation is often represented by means of visualizations and a visualization is often a simulation of some information. This is not always the case however: A visualization can represent information without simulating something, and a simulation can be performed without extensive visual feedback. In this thesis I most often use the terms as a pair, referring to "visualization and simulation technology", but sometimes they will appear on their own. In these cases, it is not critical whether the application uses both visualization and simulation or has more of one than the other. This section offers an overview of the use of simulation and visualization technology for training and education, for planning and with a certain focus on the aspect of fidelity.

Visualization and simulation technology for training and education

Visualization and simulation technology has long since been used for training and education. The most widespread example is probably in aviation where the use of full-scale environments in which pilots train actual flight maneuver scenarios is standard. In healthcare this practice has also spread and many hospitals now have a simulation training center of their own. Simulation for training is usually acknowledged for allowing practitioners to learn in a realistic environment without putting a patient's safety at risk. In times of cost savings and reduced resources for training in the actual clinical context guided by a skilled practitioner, the use of simulations for training is gaining more attention and resources.

The visualization and simulation systems range from physical models of the human anatomy on which different procedures can be trained, to completely computer-based systems in which virtual anatomical models are generated using computer graphics. There are certain disciplines in healthcare that have adopted this way of working and where simulation systems are widely used for training. Surgery, and especially minimally invasive surgery, is one such discipline in which simulation training has been found suitable for the practice of procedural skills, and it has been shown in studies that using these systems generates skills that are transferable to the operating theatre (Dawe et al., 2014; M. P. Thomas, 2013). In this area you can find commercially available simulation systems such as the *MIST VR* (Taffinder, Sutton, Fishwick, McManus, & Darzi, 1998) and the *LapSim* (Ro et al., 2005), both of which are computer-based systems designed to teach and assess basic and advanced minimally invasive surgical skills. There are also a multitude of other applications such as systems specialized in colonoscopy, biopsy or cataract surgery. These systems are often connected to the actual tools used during the surgical procedure, making it possible to interact with the computer generated models in a realistic way. This interaction can be realized using haptic feedback, which basically means that the user receives tactile feedback from the virtual objects, and thereby is able to virtually feel the objects.

Another area in which simulation has been embraced is for team training in trauma care or surgery with the aim of improving communication in a multi-professional team. In these simulation exercises the focus is on role playing around a specific scenario, which is often performed in an environment that is a copy of the real setting including a mannequin and possibly other simulation systems that can be integrated in the scenario. A facilitator controls the simulations. Video recordings of the activities and a debriefing session in which the team receives feedback and discusses the completed scenario are also carried out.

Visualization and simulation technology for planning

The application of visualization and simulation technology in planning is common when it comes to the construction sector where a multitude of information needs to be managed in the decision-making process. One approach is the *building information modelling* (BIM) process which is a digital representation of a facility and its related information. It is defined as "a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle" (National Institute of Building Sciences, 2015). Although this is a digital representation including much information that can be visualized or used for simulation, the purpose of the BIM is not to involve stakeholders or end users in the process. The information is in a form that one needs to be an expert in the field of construction to understand and use it. It is not presented so that people affected by the end product of the planning process (e.g., future residents of a building, staff in a work organization, or citizens of a community) can take an active role in the process through the material in the model.

What is of interest for my research is to explore how visualization and simulation technology can be exploited to do exactly this – involve stakeholders of various kinds, help elicit their knowledge and desires, and make them active partners in the process. A range of tools and methods have been adopted and proven useful for the purpose of involving and informing a planning process through visualization and simulation technology (Al-Kodmany, 2001; Lawrence, 1993), where interactivity has also been highlighted as a central factor for enhancing participation in a process (Schroth, 2007).

I would like to briefly mention five methods used in participatory planning processes that are based on visualization and simulation technology and that have been adopted in the empirical research of this thesis. Two-dimensional (2D) blueprints (Fig. 2, top left) are a standard tool in a planning process to visualize a facility proposal. They can be difficult to interpret in a participatory process involving people that are not planning professionals. Three dimensional (3D) models, such as physical scale models or digital models, can be used to extend the 2D drawing with a third dimension (Fig. 2, top right), which may be easier for laypeople to work with.

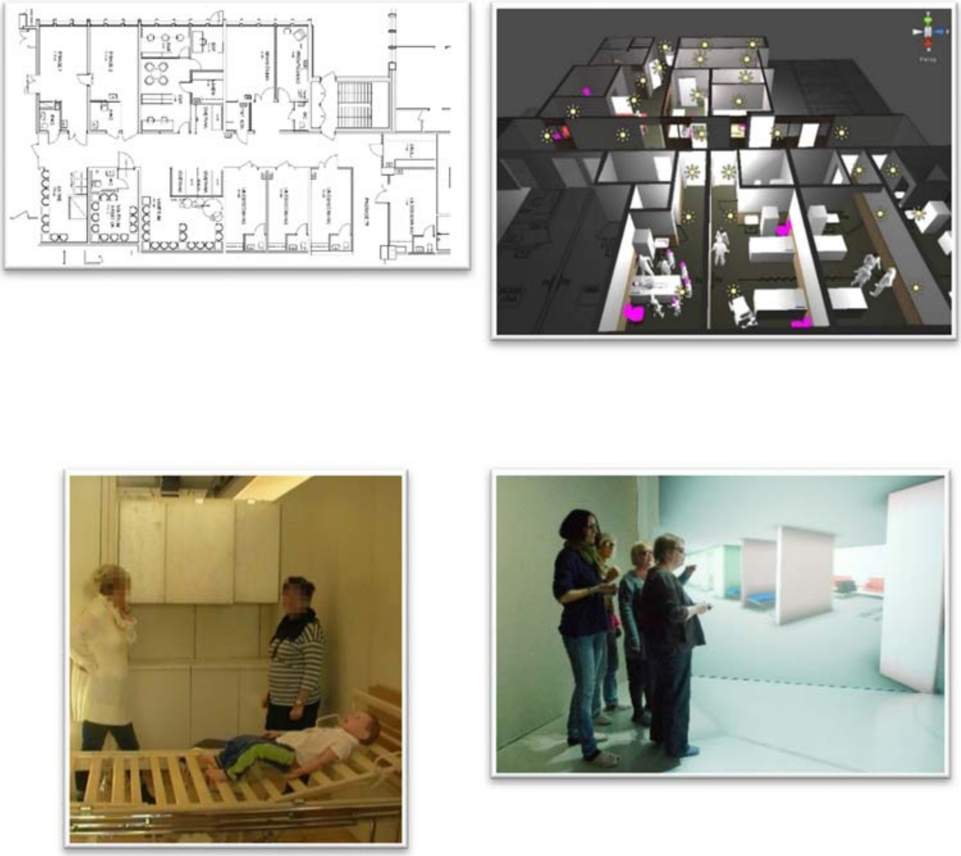

Figure 2. Examples of virtual and physical models used in planning processes: 2D blueprint (top left), 3D digital model (top right), physical full-scale model (bottom left), and virtual full-scale model (bottom right).

Full-scale models simulate the design proposal on a scale of one-to-one and may be both physical (Holmdahl & Lanbeck, 2013; Lawrence, 1993; Watkins, Myers, & Villasante, 2008) and digital (Davies, 2002; Wahlström et al., 2010; Westerdahl et al., 2006). These models are interactive in the sense that the participants may be fully immersed and can move around in and experience the model with their bodies. In a physical full-scale model (Fig. 2, bottom left) the participants may tangibly feel the model and influence it directly by moving walls or furniture. A digital full-scale model can be experienced in a fully immersive virtual environment (Fig. 2, bottom right). The virtual model cannot be modified in real time in the same way as the physical one, but is not limited in physical space or by the restrictions of the real world and can hence be used to explore in ways that are not possible in a physical model.

Another type of simulation that has been widely used in hospital planning involves viewing the organization as a complex system that can be analyzed through discrete event simulation (Jacobson, Hall, & Swisher, 2013). This method is mathematically based and provides figures and statistics on how changes in the systems can affect the outcome. It is mainly visualized using conceptual models such as the one shown in Fig. 3, while 3D graphics may be used for a more intuitive visual feedback. When using this methods in a hospital planning process, the outcome could be information about the number of patients flowing through a specific clinic or the utilization of some specific resource.

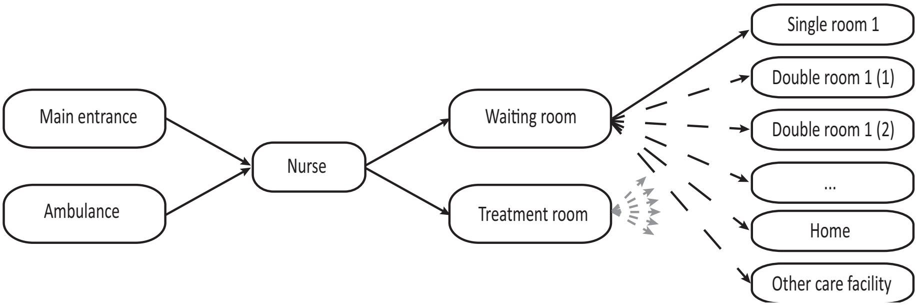

Figure 3. Conceptual model of a discrete event simulation.

Fidelity in visualization and simulation

In all visualization and simulation environments the level of fidelity is a central element. Fidelity refers to the degree of realism of the system (i.e., the extent to which it replicates the real situation). The discussion about visualization and simulation fidelity is not new but is highly relevant for the application of the technology due to its relation to the transfer of learning and to how it influences a design process. There are several types of fidelity, such as visual fidelity, physical fidelity, psychological fidelity, task fidelity and context fidelity. A good overview can be found in Liu, Macchiarella, & Vincenzi (2008). A simulation can have high fidelity in one area (e.g., replicating the visual and auditory environment well and thereby having high visual-auditory fidelity), and low fidelity in another (e.g., not replicating the actual physical context in which the activities are usually performed and thereby having low context fidelity). An insight from reviewing studies on simulation fidelity is that there is a vast number of concepts referring to different aspects of fidelity and that there is no consensus on exactly what each concept means. While "functional fidelity" is considered most important in one study (Hamstra, Brydges, Hatala, Zendejas, & Cook, 2014), a variant of this called "operational fidelity" can be emphasized in another , and still it is not clear in a given study exactly what is included in the concept (M. J. W. Thomas, 2003).

Intuitively, one might assume that the higher the fidelity the better. But a linear relation between higher fidelity and increased learning has not been shown (Alessi, 1988; Hays & Singer, 1988). Despite this, technological developments have created a trend of simulation systems with higher and higher fidelity represented by realistically rendered anatomical models and haptic tools for tactile feedback. These types of simulation systems may be motivated and beneficial for certain applications but there is a gap between these technically advanced simulators and other systems with lower fidelity that still have a high potential for training certain aspects in healthcare (Kneebone, 2005). The implication is that the level of fidelity needs to be adjusted to each specific application to ensure it matches the learning objectives, user needs, and the context of use. Some research has even proposed that the term "fidelity" should be abandoned altogether since the focus on it emphasizes technological advances and physical resemblance rather than principles of educational effectiveness (Hamstra et al., 2014).

In a planning or design process the visualization and simulation models can be seen as a form of hands-on prototypes that are used to enable discussions among the participants; the fidelity is then highly related to where in the process the models are used and for what purpose. Fröst & Warren (2000) use virtual models in a planning process and conclude that they must not be fully realistic, especially in the initial phase of the process. At this point the models serve as a catalyst for discussion and it is important that the participants feel that they can change them. A design proposals that appears complete inhibits the participants' will to explore and modify the proposal (Rogers, Sharp, & Preece, 2011, p. 392). Low-fidelity models offer a relatively inexpensive way to evaluate different suggestions since changes may be introduced without being very resource demanding, while a high-fidelity model can, in line with this way of working, be useful in another part of the process for reviewing design details. An example can be found in Dunston et al. (2011) where details in the design of a facility proposal could be verified, such as checking that certain areas were accessible, doors could be opened and bed sizes were suitable.

Human factors and human-computer interaction

The perspectives of human factors technology has served as a basis for this thesis. This is a broad area that deals with how people interact with, are influenced by and influence their environment, as well as the people within it and the technology they encounter. The International Ergonomics Association defines the field as follows:

> Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance. (International Ergonomics Association (IEA), 2015)

This field covers a broad area of theories, principles, data and methods and in this section I will narrow it down by presenting the theoretical context in which my research has been performed. Human factors and ergonomics (HF/E) have always been a prevalent aspect in the design and development of new tools, techniques and procedures to support the way we live and work, even though this may not always have been explicitly stated. During the second half of the 20th century human factors and ergonomics became recognized as a profession, and since then have grown to become a single research area of its own influenced by other research disciplines such as psychology, engineering, physiology, cognitive science and design (Sanders & McCormick, 1992). The application of HF/E is usually stated as being a balance between theory and practice, and it is sometimes criticized for being built only on the basis of empirical experience and common sense. From my point of view the following two principles are the most significant to bear in mind when working and doing research in this field: 1) *The human being is central* in the sense that the object being designed, whether it is a machine, an organization or an IT system, is built to serve humans and not the opposite. This idea emphasizes a human-centered philosophy throughout a process, instead of a technology-centered one. 2) *A system view is adopted*, meaning that the object being designed does not exist in isolation but in a context that also influences how it is used and accepted by the users.

This way of thinking is highly related to the research field of human-computer interaction (HCI) which has served as a basis for my research as well. HCI started off in the early 1980s as a reaction to the increasing use of computers in society and the struggle to acknowledge the need for usability[2] in the interface between humans and desktop computers. The field of HCI has since then developed from engineering research focused exclusively on the evaluation of computer interface usability to include cognitive science and the view of the human as an information processor in this interaction. It went on to evolve into a multidisciplinary field in which the interaction between humans and the environment is studied in a social and contextual framework (Harrison, Tatar, & Sengers, 2007). In *HCI Theory – Classic, Modern, and Contemporary* (2012), Rogers reports on the vast number of new theories, methods and concerns that have been imported into the field from a diversity of disciplines and backgrounds ending up in confusion among the researchers in trying to capture the core of the field: “We often find ourselves talking about the specific projects, ... and resort to using everyday examples such as the iPhone by way of illustration” (p. 11). Just as in HF/E, this has generated a research field that overlaps and interacts with a multitude of academic disciplines and design practices where the methods for data gathering and evaluation, philosophies for design and analysis, concepts, problem formulations, etc., are entangled. One cannot assume that a shared set of values exists among researchers or within their communities, which is in conflict with the fundamental idea of a research paradigm according to Kuhn (1970). The researcher’s

[2] Usability refers to “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.” (International Organization for Standardization (ISO), 1998)

perspective must be clarified to provide the lens through which the research is supposed to be viewed.

For my part, the relationship between HCI and HF/E is of interest since my research is situated in the interface between these fields and in line with Rogers, et al. (2011), I see that the two fields as approaching each other:

> We see Ergonomics and Human Factors as having closely overlapping goals with HCI, being concerned with understanding the interactions among humans and other aspects of a system in order to optimize human well-being and overall system performance. (Rogers et al., 2011, p. 11)

The research I present falls into this area. My perspective spans from the technical development of visualization and simulation technology to a more human-centered perspective in which the technology is adapted to the needs of the users and involves them as active and knowledgeable partners in the process. It is thus of greatest importance in a human-centered process to know the users, the tasks and the context of use. By the term *user* I am referring to a person who is affected by the design in some way. This can be either directly as an end user of the designed artifact or as an indirect user that is still in contact with the artifact in some way, such as a medical educator for a simulator system or a manager in charge of the planning of a new clinic. The term *stakeholder* may also be used for this purpose to involve a wider group of users who are not directly end users. The *task* or the goal of the use influences the motivation each user has for using a system or environment. For this it is important to understand not only what the tasks are but how they are performed. The *context of use* refers to "the actual conditions under which a given artifact/software product is used, or will be used in a normal day to day working situation" (Interaction Design Foundation, 2005). This can refer to a number of different contexts: the physical environment (type of building, type of room, indoor-outdoor, temperature, lighting conditions, sounds, etc.); the social context (organizational aspects, interaction with colleagues, patients and other people, or the lack of such interaction); and the activities within the environment, such as number of tasks performed simultaneously, number of distractions, stress level and workload. Taking the context into account in HCI originally came from Gibson's work on ecological psychology that influenced HCI researchers such as William Gaver (Gaver, 2008) to engage in the influence of the surrounding world on our behavior.

A human-centered perspective

While a human-centered perspective in the development and application of technical tools has been prevalent in HF/E for a long time (McClelland & Fulton Suri, 2005), and is also fundamental for the development of HCI (Rogers, 2012), it has not been a central view in traditional engineering science where a technology-centered perspective governs. There are several examples of technical systems that result in large work environment issues, or are abandoned completely, because of their inability to meet the needs of the users or the organization they are developed for. Examples of this are the electronic medical record *Profdoc Medical Office* used in primary care in Sweden (Agerberg, 2013) or the investigation support system *PUST* developed for the Swedish police (EY, 2013). This costs a lot of money and frustration for all parties and is not a sustainable way of working.

The lack of approaches to apply engineering knowledge to address human needs has recently been emphasized in a report on the role of engineering in facing global challenges by UNESCO (UNESCO, 2010).

> Engineers, more and more, have to be aware of the social and environmental impacts of technology, and have to work in complex teams, interacting and cooperating with society. (UNESCO, 2010, p. 7, quote from Gerard van Oortmerssen, President of the International Council of Academies of Engineering and Technological Sciences (CAETS))

While this report focuses on global challenges such as poverty, clean water and infrastructure, it highlights the challenge in overcoming the gap in the shaping of technology that is of interest for the issues discussed in this thesis relating to the human-centered versus technology-centered approach to design and development. What exactly is meant by a "human-centered perspective" may be debated. Bannon (2011, p. 53) points out that the term is often used in a generic way "without any commitment to an overarching conceptual framework other than a general interest in the development of complex human-machine systems that pay close attention to human and social factors."

One way of practically implementing a human-centered design (HCD) process can be found in the ISO standard *ISO 9241-210:2010 Ergonomics of human-system interaction – Part 210: Human-centered design for interactive systems* (ISO 9241-210, 2010). It describes HCD as a process that "aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques."(p. viii) The key principles of working in a HCD process can be summarized as follows (p. 5):

- The design is based upon an explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and refined by user-centered evaluation.
- The process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

This approach is appealing because it embraces my values and ideas regarding the development and application of technology. A core aspect for a human-centered perspective of development of tools and methods in healthcare (or any other professional setting for that matter) is to acknowledge that the people working in the organization – the ones who will be affected by a new design, whether it be a new technological aid, a new physical environment or a new organization – are experts on their context and consequently an important partner in the process. This so called *domain knowledge* means that each person has an in-depth understanding of their work and possesses considerable knowledge about the practical reality of that context. In healthcare the patients are another important group with domain knowledge about their interaction related to care activities. Depending on type of system the patient group may also be an important partner in the process.

Cooperative or participatory methods have been widely used in the fields of workplace development, product design and physical environment. *Participatory design* (PD) is one branch that works in a human-centered way. A recent definition of PD can be found in the *International Handbook of Participatory Design* (Simonsen & Robertson, 2013, p. 2):

> Participatory Design 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" (Schön, 1983). The participants typically undertake the two principle 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.

A PD process is characterized by the will to make environments and products more responsive to human needs by allowing the people that will be affected by the design take an equal part in the design process. The PD movement has one of its roots in the civil rights movements of the 1960s (Arnstein, 1969; Sanoff, 2000) with the aim to empower communities to have more influence on public decision-making. The other root stems from the Scandinavian tradition of empowering workers' influence over the introduction of new technology in the workplace (Ehn, Kyng, & Bjerknes, 1987) starting in the early 1970s. This initiated a discussion about how to change the attitudes in the technical community of system development and software engineering from a technology and product-oriented view to a more needs-driven and process-oriented one (Floyd, 1987). In 1985 Gould and Lewis presented a *user-centered design* (UCD) approach for involving users in a system development design process with three central characteristics (Gould & Lewis, 1985):

- *Early focus on users and tasks* – Understand the user's cognitive, behavioral, anthropometric, and attitudinal characteristics, as well as the nature of the tasks to accomplish.

- *Empirical measurement* – Observe, record and analyze user's interaction with simulated, prototyped or real versions of the system.
- *Iterative design* – A cycle of design, test, measure, redesign, etc., to evolve from sketches, via prototypes towards the real system.

The way of involving the user in a UCD process, as presented by Gould and Lewis, does not necessarily mean that end users are involved as active participants. Although the emphasis is to let users have an influence, this is sometimes achieved through indirect methods such as personas or scenarios, that is, without any direct involvement of the users. Observations and interviews increase the users' interaction in the process somewhat, while methods that allow the users to have a larger influence in the process, such as building and evaluating prototypes, take the user involvement one step further. This approach may seem submissive because there is no discussion of how the choice of methods or implementation of the process will affect the level of user-centeredness and user empowerment, something that is central in the participatory design community. But when presented in 1985 to the computer system development community, this approach proposed quite an original way of working. This is highlighted by the authors in a discussion about how these rather obvious statements can be very hard to implement in practice. For people with a background in design or architecture, it may be considered obvious to work in this way, while this approach is still not common practice in engineering and system development 30 years after the publication of the article.

Design methods for eliciting and sharing knowledge

Design activities involving different stakeholders require methods for bridging communication gaps between different knowledge domains. Much of the theory in participatory design, for example, relates to methods, techniques and tools for doing this (Simonsen & Robertson, 2013). At the most simple level one can separate external and internal knowledge domains, where the external represents the people coming from outside the organization (e.g., architect, system developer, or designer), while the internal would represent the knowledge coming from within the organization. There is however a great diversity in the knowledge in each of these categories as well. Healthcare is made up of many different professional roles with strong work identities organized in an informal hierarchical structure (Thunborg, 1999). There is a mix between the knowledge obtained through education and knowledge obtained through practice, the latter of which may be defined as tacit knowledge to some extent. *Tacit* here refers to knowledge that cannot easily be verbalized or communicated since it is built into the actions of the person who possesses it – "we can know more than we can tell" (Polyani, 1966). On the other hand, explicit knowledge is something that may be verbally expressed more clearly and hence more easily communicated. In practice these two types of knowledge are constantly interacting and one cannot always say that either one or the other is used. By applying certain activities, the tacit knowledge can be made explicit and then shared with others and can be used to inform a design process of some kind (Brandt, Binder, & Sanders, 2013; Eraut, 2000).

Throughout the years design research (including interaction design research and participatory design research) has worked with numerous methods to bridge the gaps between different knowledge domains and to elicit people's knowledge and mental models. Participatory design aims to create a temporary community in which a mutual understanding for the design task and a shared language around it is developed to reduce communication gaps. Tools and techniques that enable telling, making and enacting are adopted in the process (Brandt et al., 2013), ranging from verbal activities, brainstorming, sketching, building prototypes, creating scenarios, enacting scenarios, etc., to envisioning a future design. Some of the tools and materials that can be helpful in these design activities are paper, pencil, whiteboard, sticky notes, computer simulations, visualizations in two or three dimensions, clay, construction material, miniature models, full-scale virtual or physical models. These "design-by-doing" methods are mediating objects that enable the stakeholders to make their own work experiences and knowledge more explicit (Eraut, 2000) and encourage the participants to take a more active role in the design process by using their practical skills (Ehn, 1993).

Research design, methods and data analysis

This chapter presents the research design and methods used in the various studies. An overview of the studies and relevant methodologies are presented initially, before continuing with the research processes for each case and how specific methods were used to collect data. Finally, the analysis of the data is presented.

The research process and methods have been different in the studies. In case 1, quantitative, mathematical methods were applied, while case 2 and case 3 were performed in a methodological multidisciplinary context where qualitative methods were part of the process. In light of this it is important to provide information about the entire process so that the findings may be evaluated in relation to the procedures used to generate them (Graneheim & Lundman, 2004), which is the aim of this chapter. An overview of the cases and the methods used for data collection and analysis is found in Table 1.

Case/Paper	Purpose of data collection	Type of data	Data use and analysis
Case 1 Paper Ia Paper Ib	Understand the degree to which the bones from computer tomography data was successfully segmented with the applied segmentation algorithm.	Segmented data from computer tomography scans.	Degree of successfully segmented bones were analyzed to understand how to tweak the algorithm for better results.
Case 2 Paper II	Part of a participatory design process.	Observation through shadowing Iterative prototyping	Used in the participatory design process to iteratively form the design. Qualitative analysis and interpretation to guide the next step of the process.
	Documentation of the user-centered evaluation.	Observation through video recording and think aloud Interview Questionnaire	All data was analyzed as a whole with a thematic approach.
Case 3 Paper III	Follow-up of the project participants' experiences.	Interview	All data was analyzed as a whole with a thematic approach.
	Documentation of the workshop.	Direct, participatory observation documented with video recording. Questionnaires	
Paper IV	Literature review	Publications relating to the research questions of the review.	Publications were retrieved and analyzed qualitatively.

Table 1. Overview of data collection for the included papers: their purpose, type and data analysis.

Research approaches

Case studies

Case studies aim to generate knowledge by examining in greater depth one or a few specific phenomena in context. Through the case study the questions of *how* and *why* are investigated for a certain phenomenon within a holistic real-world context (Yin, 2014). A case study can be characterized by four key aspects (Lazar, Feng, & Hochheiser, 2010, p. 147):

- In-depth investigations of a small number of cases.
- Examination in context.
- Multiple data sources.
- Emphasis on qualitative data and analysis.

By studying one specific case instead of a large number of different cases one can gain wider knowledge and insight into aspects that would not have become visible through other research strategies (Denscombe, 2009, p. 59). When it comes to the application of new technology, it cannot be studied with the attitude that the product or system is an isolated object, not influenced by users, task or context. This is why case studies are a useful source of information in HF/E and HCI research to exemplify and describe how the technology is implemented and used in a given context.

Cases 2 and 3 in particular fit into this description. They study a multitude of factors in each specific sub-project that the clinics were working on, departing from issues encountered in practice; with multiple data sources involving observation, questionnaires, interviews and prototyping in iterative processes; and resulting in mainly qualitative data for analysis. Case 1 does not fit equally well into this description since the focus was on the technical advancement of the simulation system itself and not on the users, task or context. In this thesis, however, I will reflect upon the research in case 1 using a more holistic view of the simulation system and the context in which it was applied.

Involving participants in design

Working participatory, with end users and various stakeholders involved as active partners in the process is a way to ensure that the focus of the design and development is kept on track throughout the process and that the requirements correspond to what those using the system on a regular basis need (Rogers et al., 2011, p. 322). As discussed in the theoretical context chapter, there are various levels of user involvement that may be adopted. Users can be assigned team leaders and be in charge of the actual process or they can be involved in specific activities on an occasional basis. There are pros and cons for these extremes and the level of user involvement and how it is implemented must be defined from the individual circumstances of the project to ensure that it supports the process in the best way and is practically viable.

In the three case studies that this thesis is built on there have been various levels of involvement. In case 1, there were two surgeons regularly involved to provide medical expertise on the application of the simulation system. In the project *Computer-aided Visualization for Learning, Participation, Planning and Change in Advanced Healthcare*, of which cases 2 and 3 were part, there was an extended, multidisciplinary, group working together including three researchers, three practitioners from the children's emergency clinic, three practitioners from the infectious diseases clinic, and one representative from the county council, exchanging ideas and knowledge related to the overall project theme as well as the two specific cases. The practical implementation of the project was organized with joint project meetings combined with lectures and study visits on various themes relating to visualization and simulation technology.

Research processes

Case 1

The studies presented in Papers Ia and Ib summarize case 1 (licentiate research) where a surgical simulator system was improved from its current state of being a generic virtual model of the hip anatomy, to one that incorporates patient specific models. This extended the use of the system from generic training to patient specific training as well as pre-operative planning. A detailed description of the development process can be found in appended Paper Ia.

There were no explicit discussions related to the users, the use context or how to involve users in the development process. The focus was on the development of the algorithms and the implementation of the patient specific data in the simulator system. Two aspects of user-involvement and iteration can be identified in the process. The first was that two surgeons were consulted to share their knowledge throughout the process as representatives for the end-user group and the application of this type of system. The second aspect was that the process itself was iterative. The first iteration involved generating models of non-fractured bones and integrating these in the simulator system (Paper Ia), and the second iteration generated models of fractured bones (Paper Ib). The second iteration also included an upgrading of the haptic interaction of the simulator and the visual feedback to advance the technical solutions, resulting in a system that simulated the surgical situation with higher fidelity than before. It was however not part of the research to analyze how the user-involvement and the iterative process affected the design of the simulator system.

The methods that were of relevance during the licentiate research related to image processing theory and methods for automatic segmentation and registration. One of them was applied and further developed, but many other could have been adopted. The overall discussion was thus related to the motivation for using the applied method, and how it was adjusted and improved for the specific purpose. In the context of the current doctoral thesis, I do not focus on the image processing part of the licentiate research. Instead, I consider the research carried out as one of three cases in my doctoral thesis. In this case I concentrate on the design and development process of the hip surgery simulation system in addition to its practical application once finalized.

Case 2

In case 2, the researchers and three practitioners from the infectious diseases clinic formed a team to design a simulation-based application for training the management of medical technology in critical care situations. An iterative design process involving the practitioners was performed including the activities presented in Fig. 4.

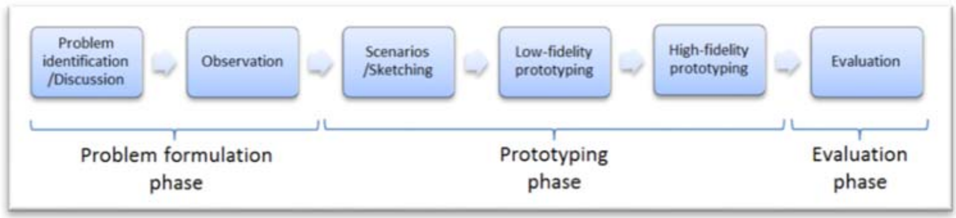

Figure 4. Activities in the participatory design process of case 2.

The research was divided into three phases with different activities. The first was a *problem formulation phase* in which the specific task that the participants wanted to work with was identified and discussed, and observations were performed by the researchers to gain an understanding of the clinical context. In the following *prototyping phase*, the concept of the simulation tool was iteratively concretized through consecutive workshops where various methods for iterative and participatory design were applied, such as scenarios, parallel design suggestions, and paper and computer prototyping. Finally, there was an *evaluation phase* in which the finalized computer prototype of the simulation system was evaluated by a larger groups of end users. The evaluation was structured so that the participants worked in pairs with the prototype while they were asked to think aloud. The process was video recorded for retrospective analysis. In addition, the participants were asked to fill in a questionnaire for individual feedback and then an interview was performed with pairs of users to gain a broader perspective on their experience of using the tool and to discuss how they currently work with continuing professional education in their clinic.

Case 3

Paper III describes the last case of the thesis in which a planning process for a new children's emergency clinic was supported through the application of a combination of simulation and visualization technologies. Fig. 5 gives an overview of the methods applied throughout the process.

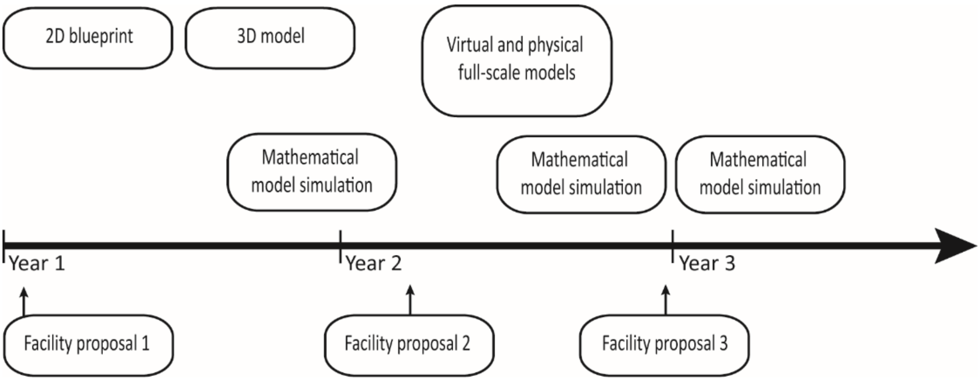

Figure 5. Visualization and simulation technology adopted in case 3.

In this process, as compared to case 2, the practitioners did not actively take part in the development of the visualization and simulation technology. This was done by the research team or students engaged for the purpose, and provided the practitioners with practical models and tools to take part of the information that was shared in the planning process, and to verbalize their thoughts about it in relation to their work. The process evolved from 2D blueprints, to 3D models on a regular desktop computer, to virtual and physical full-scale models. In parallel with these activities, simulations based on mathematical modelling were adopted. During the entire process the group was presented with three new facility proposals in total. The virtual and full-scale physical models were also used in a workshop in which more practitioners from the clinic were engaged in the process.

Literature review

The literature review presented in Paper IV was a consequence of developing the simulation tools for training in the healthcare context. From my own experience I knew that the design and development process can be very different for these systems. This evoked my interest in investigating this aspect in the research community of healthcare simulation. The result was a literature review that more closely examined the process that precedes the implementation and evaluation of simulation systems for training in healthcare. The review was carried out to see in what ways human-centered approaches had been adopted. The results are presented in Paper IV.

A database search for the research question was framed based on four themes:

1. Simulation – All types of simulation were of interest, whether they were a mannequin, a virtual environment, a serious game or an interactive web-based application. This meant that a number of terms representing these systems were used in the search.
2. Healthcare – We were only interested in simulators used in healthcare, excluding simulators in aviation and power plants, for example.
3. Training – We limited our search to simulators used for training of healthcare professionals or medical students and not for other purposes.
4. Design – Our focus was on the description or discussion of the design of these systems, involving methods to include users, a concentration on user needs and tasks, and use context. This was addressed with various search terms such as "human-centered design", "user-centered design", "participatory design" or "iterative design".

From a total of 2475 articles 25 were selected for further review based on inclusion/exclusion criteria. The 25 articles were then analyzed for type of simulation, application area, purpose and the way in which they discussed the use of a human-centered approach. They were then discussed by means of this analysis.

Data collection methods

The data collection and analysis in the empirical studies in Papers II and III were mainly of a qualitative nature to study *how* and *why* certain behaviors occur: "With qualitative research, the emphasis is not on measuring and producing numbers but instead on understanding the qualities of a particular technology and how people use it in their lives, how they think about it and how they feel about it" (Adams, Lunt, & Cairns, 2008, p. 138). There are many methods available and many ways to categorize these methods. Good overviews and detailed descriptions can be found (Cairns & Cox, 2008;

Lazar et al., 2010) and the reader is directed to this or other literature for more thorough reviews.

One approach when deciding upon a combination of methods is provided by Rogers et al. (2011, p. 261) and is based on four points of departure. The *first* states that the data collection methods must provide data that is appropriate for the focus of the study, that is, data that makes it possible to draw conclusions in line with the research questions asked. More open-ended methods such as observations and interviews can be useful in the initial part of the process while more specific methods, or methods of a more evaluating character, may be useful when the process has reached a more concrete phase. The *second* point emphasizes the participants and the context. The characteristics of the target group and the context in which the method is applied also play a role. When working with staff in a clinical context, for example, the methods must not interfere with their ordinary tasks and the time slots in which one can access the participants are often limited. The *third* point relates to the nature of the technique. If special equipment is needed or is to be evaluated, this also places requirements on the form and context of the method. The *fourth* and final point directs attention to the available resources since all studies have limited resources when it comes to such aspects as compensating participants for their contribution, the time or number of people that can analyze s or the time to create iterative design solutions and evaluate them. Here, I briefly explain the methods used, describe how they were used in the research and why they were selected.

Observations

Observation deals with the process of observing people in their real-world setting to learn about their activities, behaviors, relations, etc. It is a useful approach to get to know an environment that you are not usually part of. Observations can be done in the early stages of a design process to create an understanding for needs, limitations and preferences of the users situated in the use context. Observation is also often used as a data gathering method when evaluating a design by letting users interact with the new device while researchers make direct or indirect observations of the situation.

There are several different approaches to observations: they can be direct or indirect and more or less participatory. Direct observation is when the participants and activities are directly observable by the researcher either by being in place and observing in real-time or by looking at video recordings. Indirect observation is when the participants' activities are tracked through other sources such as diaries or interaction logs. In participatory observations the researcher has a more active role and may interact with the participants during the observation, while in a non-participatory observation, the researcher is as invisible as possible or video records the activities for retrospective analysis (Rogers et al., 2011, pp. 247-260). A specific form of non-participatory observation is shadowing. This is a contextual observation in which the observer follows a specific person (or object) through space and over time during everyday activities (Czarniawska, 2014, p. 66).

Shadowing was used in the initial part of the design process of case 2 to increase the understanding of the clinical setting by shadowing the practitioners during their work shifts. Later in this study video recordings were used along with the think aloud technique as a way to examine how the participants interacted with the prototype and to connect the think aloud statements to the activities in the interaction, without interfering with them during the actual interaction. Think aloud is frequently utilized in user evaluations in HF/E and HCI (Rogers et al., 2011, pp. 256-258). The users are encouraged to speak their thoughts out loud while using a product or system. In this way the investigator obtains more feedback about what the users think in each specific situation and why they act in a certain way. Since people are not usually comfortable with talking aloud to themselves while someone sits and listens, it may be difficult for them to actually do so. By letting the users work in pairs it can be easier for them to express their thoughts in a dialogue with the other user, which is why we choose this approach in case 2. Working in pairs was additionally beneficial in eliciting the users' knowledge and expectations of the different situations that they encountered in the interactive simulation.

In case 3, participatory observations were carried out during the workshop to observe the participants' interaction with the visualization and simulation technology. By means of video recording, I as researcher was able to be an active participant in the activities and not have to stand in the background and take notes.

Questionnaires

A questionnaire is a well-defined set of questions that the respondents either answer on their own or in collaboration with the investigator. The advantage of using a questionnaire is that it is an easy way to gather data from a large number of subjects and the answers are structured so that they are easily merged and compared. A questionnaire can contain both closed and open-ended questions that generate a greater variety in the answers. Another advantage is that it can be used to generate feedback anonymously from the participants in, for example, an evaluation of an interface, so that the respondent can feel free to express criticism that would not have been revealed otherwise. Since it is not possible to ask any follow-up questions on a questionnaire, it can be wise to combine it with an interview or ways to retrieve feedback by other means in order to gain a deeper understanding of the answers.

A questionnaire was used in case 2 to obtain individual feedback on the experience of using the simulation prototype, as opposed to the subsequent interview that was done in pairs and had a broader perspective. The questionnaire consisted of three sections: one related to the background and computer experience of the respondent, one related to the usability of the prototype by means of the System Usability Scale (SUS), and one with more open-ended questions about the usage.

The SUS is a common method for measuring the usability of a system (Brooke, 1996). Despite its "quick and dirty" approach it has become a widespread method for assessing the users' subjective impressions of using a system. It consists of ten statements that the respondent either agrees or disagrees with on a five-point Likert scale. The statements relate to various aspects such as the need for support, training, and complexity, which provide a high level of face validity in the method. Its use in the evaluation of the prototype in case 2 gave good insight into the usability aspects of the design and experience of usage. This part of the questionnaire is quantitative since it is summarized in a numerical score for each statement that tells how much the users agree with that statement. The results from the SUS feedback provided insight into various aspects of the design of the prototype that could be translated into requirements for further improvement of the design and content.

A questionnaire with open-ended questions was also used in case 3 to gather information about the participants' experiences of taking part in the workshop and utilizing the different visualization and simulation technologies.

Interviews

Unlike questionnaires, interviews offer a way to gain a more in-depth, comprehensive perspective of the subject's point of view by having a guided conversation with that person (Kvale & Brinkmann, 2009). You are also able to ask follow-up questions to learn more. Interviews can range from being structured, using an interview protocol that you follow strictly so that basically every interviewed person gets the same questions, to being unstructured and based on a more thematic approach where no strict guide is followed. The latter allows for a more open conversation, but the data gathered is not organized in the same way as for a strict interview.

Semi-structured interviews were used in case 2 in the prototype evaluation phase as a complement to the questionnaire for three purposes: to get a deeper perspective of 1) how the participants perceived working with the prototype, 2) how they usually work with professional development, and 3) the approaches they have for sharing knowledge in the staff group. In case 3, the same type of interview was used in an initial stage to interview the three project participants about their comprehension of using the first 3D digital model that was developed.

Prototyping

The purpose of prototyping is to explore and evaluate design ideas using concrete implementations of the design proposals. Prototypes may range from low to high fidelity depending on how close in appearance and functionality they are to the final product. They can span from being paper-based such as sketches or paper mock-ups, to being computer-based using tools in which sketched implementations of the design can be created (sometimes referred to as medium-fidelity prototypes), to being computer-based versions that from a user perspective appear and function very much like the final product even though the technical implementation is not completed. The division into low- and high-fidelity prototypes is well established while a strict categorization is not necessary. The important thing is to create a prototype that is most relevant for the design activity (Rudd, Stern, & Isensee, 1996). Low-fidelity prototypes can be good for testing design concepts without a time consuming development phase. It is easier for the user to understand that the design is under construction and still possible to influence when the prototype does not look like a finished product. High-fidelity prototypes, on the other hand, are useful for presenting a more complete user interface and to evaluate it in a realistic context. Prototyping is particularly important in a participatory design process where the people involved often have different frames of references and different terminology. The prototype is a means to reach a common understanding of the user requirements.

In case 2 we used low-fidelity prototyping to identify and sort among design concepts, and continued with high-fidelity prototyping, where a fully interactive representation of the application was created. Two techniques were used in the low-fidelity prototyping phase: storyboards (or sketching), and paper mock-ups. The storyboards enabled the participants to visualize scenarios in their work that could be of interest for this type of educational tool and paper mock-ups were used to evaluate different design concepts in the work group. This provided input to the high-fidelity prototyping phase. The computer-based, high-fidelity prototype went through a number of iterations as well before reaching a version that was ready for evaluation.

The models that were used in the process in case 3 – the 3D virtual models and the physical model – are also examples of prototypes since they are concrete implementations of the suggestions studied and are used in the process with the same purpose as a prototype.

Data analysis

The data was analyzed in a bottom-up fashion with qualitative content and thematic analysis methods. The aim of this inductive approach was to move from specific instances in data to a larger whole from which more general conclusions could be drawn. Working with the data in this way means that the researcher's subjectivity is an essential part of the production of an interpretation and measures need to be taken to reduce this influence (Cairns & Cox, 2008, p. 139; Graneheim & Lundman, 2004). The following four guiding principles for the researcher that were followed offer a way to strive for trustworthy results in which the subjectivity of the researcher is reduced (Denscombe, 2009, pp. 367-369). The first principle is fundamental for all research: *1) The analysis and hence the conclusions should be well grounded in data*. This means that all abstract reasoning or non-grounded assumptions are not trustworthy results of a research study. The second and third principles relate to the subjectivity of the researcher: *2) The researcher's explanation of the data should come from a thorough reading of data,* and *3) The researcher should avoid introducing unjustified prejudices*. These principles emphasize that a qualitative research approach always involves some kind of interpretation of the data by the researcher and s/he must be aware of the ways his/her prejudices bias the interpretation and minimize this influence by ensuring that the explanations provided are deduced from the empirical material. *4) Data should include an iterative process*, which means that the analysis is not a linear process but oscillates between moments of clarity and moments of disorder. As the researcher works with the data, themes and patterns flow back and forth to eventually form a fine-tuned version of the results.

The research in case 1 was not performed in a qualitative manner and is hence not analyzed according to the above described principles. In case 1 (Papers Ia, Ib), the data was analyzed by evaluating the segmented bone to understand how well the segmentation algorithm worked. To some extent, however, a subjective interpretation was also made since no comparison to a gold standard (such as a manual segmentation of the bone) or to other segmentation algorithms was carried out.

In case 2 there were two different processes in which data was used and analyzed. The first one related to the ongoing design process in which the observations, storyboards, prototypes, etc., were analyzed and evaluated, and the findings from one step were used as input to decide upon the next action, as well as to guide the design decisions. The second process was to analyze the data collected in the user-centered evaluation. This data consisted of video recordings of the users working with the prototype while thinking aloud, a questionnaire and interview data. Some aspects were recognized as interesting themes before the study was conducted, such as what the prototype triggered for discussions related to the corresponding real work situation (which was also a reason for letting the users work in pairs to trigger them to talk to each other about the activities in the simulation), the usability of the prototype, the attitude towards this type of tool for education, and the way they currently organized their continuing education or professional development. The principles of content analysis guided the data analysis. Patterns and themes in the various sources of data were identified based on frequency (how often they occurred) and significance (how important they were considered to be) (Cairns & Cox, 2008, p. 147). Video recordings were viewed several times and the participants' thinking aloud records, and the interviews were transcribed. The open-ended parts of the questionnaire were integrated into the qualitative material while the quantitative parts were compiled and analyzed using descriptive statistics to find central tendencies and variability (Lazar et al., 2010, pp. 73-74). Excerpts from the qualitative data that was considered to form meaning units (Graneheim &

Lundman, 2004) were extracted and grouped into categories and subcategories that after some iterations resulted in the themes in the results and discussion of this study. This involved both the themes that had been identified before the evaluation and the themes that emerged throughout the analysis. This process was practically implemented using the *Nvivo* software.

The process in case 3 had some data collection points along the way. The practitioners that were part of the research project continually provided feedback on the activities in the process through reflective discussions that informed the process along the way and helped decide which actions to take next. At one point a more structured interview was held to evaluate the use of 3D models as part of the planning process. Other data was collected during the workshop in which these three practitioners and nine additional practitioners participated. Since the material to a large part consisted of video recordings of people acting in a virtual or physical environment, the analysis had to include more than just the spoken words. Gestures and other signs of interaction among the participants or between the participants and the environments were also of interest for the analysis. A similar approach to case 2, using the principles of content analysis, was applied to form themes of interest for discussion, where the meaning units could be derived from spoken words, open-ended questionnaire answers or physical activity in the models.

Summary of appended papers

This chapter summarizes the appended papers. In total there are five: two from the licentiate time and three from the current research setting. One is a conference paper and four are journal papers of which three are published and one is submitted for publication. For each paper I present the aim, method and results of the paper and how it contributes to the overall aim of the thesis.

Paper Ia

A Hip Surgery Simulator Based on Patient Specific Models Generated by Automatic Segmentation

J. Pettersson (author's birth name), H. Knutsson, P. Nordqvist and M. Borga

Presented at Medicine Meets Virtual Reality 14 (MMVR), *Studies in Health Technology and Informatics*, 119, 431-436 (2006)

This paper presents a framework for automatic segmentation of the hip bones using a method for non-rigid registration called the morphon method (Wrangsjö, Pettersson, & Knutsson, 2005). The application is a surgery simulator system to train the surgical procedure for cervical hip fractures when the femoral neck is fractured, which is a common injury and hence a common orthopedic procedure. The simulator provides visual, haptic and audial feedback to produce an environment that resembles the real operation environment (Fig. 6). The user interacts with the system using real surgical tools. Different tools such as guide wires, drills and step reamers are used for positioning and insertion of the nails. The visual feedback is presented in the form of simulated fluoroscopy images that are used to check the progress of the surgery (right part of Fig. 6), controlled through interaction with the pedals.

In the original system, one handmade polygon model based on generic data was implemented. This study extended the simulator to include patient specific models, generated from computed tomography (CT) data of different patients. This was achieved through an automatic segmentation of a number of CT datasets from various patients. The hip and pelvic bone in the segmented datasets can then be extracted into a 3D model that is imported into the simulator and used for training. By means of this

Figure 6. The hip fracture surgery simulator system replicates a real surgical environment (left) and the visual feedback is provided through simulated fluoroscopy images (right).

process the simulator system was improved from having one generic model of a hip bone into a system offering patient specific models generated from real patient data.

The result is thus a simulator system of higher fidelity concerning the anatomical models. The use of patient specific models instead of one generic model increases the realism of the simulation. Studying whether this increases the degree of learning from using the simulator was not part of the study.

Paper Ia contributes to this thesis by exemplifying the use of visualization and simulation technology for training in healthcare. The system is typical for simulator systems in surgery, where interaction through visual and haptic feedback is adopted to create a high-fidelity system, replicating the real situation for this type of surgery. The expansion of the original system by adding patient specific models broadens the system's area of use by offering more hip models to train on.

Paper Ib

Simulation of Patient Specific Cervical Hip Fracture Surgery with a Volume Haptic Interface

J. Pettersson (author's birth name), K. Palmerius, O. Wahlström, B. Tillander and M. Borga

Published in *IEEE Transactions on Biomedical Engineering*, 55(4), 1255-1265 (2008)

The main difference in the study presented in this paper from Paper Ia, is that the algorithm was modified to also handle fractured bones. In addition, this study introduces a novel method for tactile feedback based on volume haptic interaction that makes it possible to generate haptic feedback directly from the patient's CT dataset. The simulated visual feedback was improved by adopting volume rendering techniques so that characteristics similar to the real fluoroscopic images were achieved.

The result is a simulator that can replicate real-life fractures for surgeons or students to train on. The application of the simulator is furthermore extended such that it can be used as a pre-operative planning tool, i.e. before performing the surgery on a patient the procedure for that specific fracture can be planned in advanced in the simulator.

Paper Ib is based on the same case as paper Ia. It contributes to this thesis by showing how an iterative process was adopted to further improve the system by expanding the patient specific, non-fractured model described in Paper Ia, to this final version with both patient specific and fractured models of the hip bone for training and pre-surgical planning. The research still has a technology-centered focus, advancing the technical features and hence increasing the fidelity of the system. No evaluation of the attitudes and learning outcomes from using this system compared to traditional ways of training, or compared to the original version of the system was part of the project.

Paper II

Evaluating Interactive Computer-based Scenarios Designed for Learning Medical Technology

J. Persson, E. Dalholm Hornyánszky, M. Wallergård and G. Johansson

Published in *Nurse Education in Practice*, 14(6), 579-585 (2014)

The aim of this paper was to understand how visualization and simulation technology can be used for training in a healthcare context in which this technology is not traditionally used as a tool for learning (unlike the surgical context of the simulator in case 1). The application is an interactive computer-based tool with simulated scenarios for practicing the use of medical technology in the critical care context. This tool is an example of how to expand the resources for professional training beyond the more traditional educational material, such as text-based material, case descriptions and product manuals, without moving to technically advanced and resource-demanding simulation-based training, such as full-scale team training or virtual reality-based skill simulators.

An important aspect of this study was the methodology adopted, which had an explicit focus on a human-centered approach where the users, their needs and tasks, and the context helped to shape the resulting design. The practitioners and their colleagues were concerned about critical situations for the respiratory intensive care patients and the lack of risk awareness about certain activities concerning these patients and their monitoring, life-supporting devices. This resulted in the idea of an educational aid for training the use of medical technology in the patient care context. In relation to this, it was also found that they needed a tool that would be available in the clinic, that would not require a lot of resources, and that everyone could use despite differences in experience, educational level, and language skills.

The practitioners were active partners in the design process to create a computer-based prototype that illustrated the concept of the training tool. The evaluation showed that the participants were engaged in using the prototype and their discussions demonstrated the use of the tool as a platform for sharing and co-constructing knowledge. Their comments and ideas for improvements were also considered useful for a continuing development of the prototype.

The participatory design process helped to frame the relevant questions and adjust the form and content of the prototype to the needs and context of the users. It also helped to create an educational experience situated in the local practice of the specific clinic, while still providing general knowledge for similar situations. This would not have been possible without access to the domain specific knowledge of the practitioners and their active involvement in the process.

Paper II contributes to this thesis by providing another example of how visualization and simulation technology can be used for training in healthcare. This example is different from the hip surgery simulator in case 1 because it was implemented in a context that does not usually work with these types of tools for education, and because it allowed a participatory design process guide the design and development.

Paper III

Informing Hospital Change Processes Using Visualization and Simulation Tools

J. Persson, E. Dalholm Hornyánszky and G. Johansson

Published in *Health Environments Research and Design Journal*, 8(1), 45-66 (2014)

This paper demonstrates the use of visualization and simulation technology to involve stakeholders and inform the process of planning new facilities for a children's emergency clinic. A combination of various visualization and simulation technologies was used throughout the process to study how they could contribute to involving participants from the clinic, elicit their domain knowledge as well as their needs and desires for the new facility, and use this to inform the ongoing process.

The first visualization and simulation technology that was used was a digital 3D model that the practitioners could interact with on a standard PC. This was followed by a workshop including full-scale virtual and physical models. Nine additional practitioners from the participating clinic attended the workshop and could thereby influence the process with their knowledge and ideas. Mathematical model simulations, in the form of discrete event simulations, were used to evaluate specific aspects of the different designs in parallel with the other visualization- and simulation-based activities.

This process was not set from the beginning. Depending on the information that came out of one activity determined the next step. The outcomes of the overall process were both concrete suggestions of how to change the facility proposal (fed back to the hospital planning team along the way) as well as more knowledge about how visualization and simulation technology contributed to the process. The following points summarize the main aspects when transforming the results to implications for practice:

- The visualization and simulation technology helped to elicit the practitioners' knowledge such that it could be used in the planning process to make more informed decisions.
- The models, whether digital or physical, do not have to be realistic replicas. A low-fidelity model is a good catalyst for discussion because the participants feel that they can modify the proposal. Changing the model is not particularly resource demanding.
- A combination of tools adds value to the process by eliciting questions from various angles by means of different methods.
- There is still a long way to go before the technical tools are simple enough for non-experts to use. Organizations need to provide the human and technical resources required to support this way of working. Continuity is also a benefit for working with these tools within the hospital organization.

Paper III makes a somewhat different contribution to this thesis since the previous studies relate to the explicit use of visualization and simulation technology for training in healthcare. In this study the technologies were used as methods to support a human-centered planning process.

Paper IV

Simulation in Healthcare – From Technology-centered to Human-centered Design and Development

J. Persson

Submitted for publication (2015)

This paper examined the processes that precede the implementation and evaluation of simulation systems for training in healthcare. The perspective of a technology-centered versus a human-centered approach became visible to me by reflecting upon the processes in the other studies in my thesis research. Examining this in the related literature strengthens the conclusions that can be drawn. Paper IV presents the results of a literature study that reviews healthcare training simulation publications with focus on the presence or absence of discussions about the design process, as well as the role of the users, tasks and use context for such systems.

Publications related to the study questions were retrieved from a set of databases and analyzed. The publications included were those:

- that contained a description or discussion of a design or development process using methods for user involvement or in other ways related to human-centered design methods,
- or that focused on understanding how simulations are used and how they can be better adapted to users, tasks and use context.

The publications excluded were those:

- that were only concerned with the technical improvements of existing systems,
- that addressed the development or implementation of a curriculum for simulator systems,
- or that presented summative evaluations of a finalized or curriculum-integrated simulator system.

The number of research articles included in the final review was low. It became clear that not much has been written discussing these specific aspects compared to the vast number of articles published about simulation systems for training in healthcare in general. The review concludes that the focus on human needs in the development of simulation systems for training in healthcare is currently insignificant. Although a human-centered design approach is used and described, the level of participation and human-centeredness varies considerably, from almost non-existent to more regular involvement of practitioners and multidisciplinary teams throughout the process. Less focus on technical advancements in favor of the needs of the users and the healthcare community, as well as more publications describing the underlying process instead of including technical descriptions and summative evaluations, can help in the process of creating simulation systems for training in healthcare that are: 1) relevant to the learning objectives, 2) adapted to the needs of users, context and task, and 3) not selected based on technical or fidelity criteria.

Paper IV contributes to the aims of the thesis by highlighting the use – or lack of use – of human-centered perspectives in the design and development of visualization and simulation technology for training in healthcare.

Discussion

This chapter presents principles, relationships and generalizations derived from the appended papers and discusses these in relation to the research aims of the thesis. Implications for practice are considered in order for people in healthcare practice to be able to assess and apply the results. Methodological considerations are discussed to enable the reader to evaluate the chosen research approach, the quality of the results and my development as a researcher.

Applications of visualization and simulation technology

The first aim of this thesis is to increase the knowledge about using visualization and simulation technology for training, planning and participation in the healthcare context. The research aim is motivated by the potential that visualization and simulation technology can be a useful tool for these purposes in an organization continuously exposed to changes.

Visualization and simulation technology for training and education

Examples of two quite different applications for how the technology can be used for education in healthcare have been demonstrated.

The case 1 project presents a typical example of the technical development of a simulator system applied in surgery training. The hip surgery simulator in case 1 was motivated because this surgical procedure is highly dependent on hand-eye coordination and procedural skills that can be trained in a system like this. In this sense, the simulator system offers new ways of learning that were not available before for this specific procedure. The development of similar systems is hence motivated for training per se, and the combination of visualization and haptics is then natural for training the procedural skills of a specific type of surgery. With the extension of this system to incorporate patient specific models of fractured bones, the use of the application was expanded to become a preoperative planning tool, which enables the personnel to prepare surgery in greater detail and decrease the risk of unexpected circumstances arising during the actual surgery.

The example in case 2 is a somewhat different application since it was not developed for a discipline that normally uses visualization or simulation technology for training. The target users are nurses, assistant nurses or doctors, and the learning objectives are related to the development of decision-making skills and the ability to evaluate the course of event, rather than practical hands-on skills for managing a specific piece of equipment or a certain procedure. With this example I want to highlight that visualization and simulation technology can also be useful for training in disciplines where this is not commonplace and where the culture is not used to these type of tools for continuing professional education, compared to surgery where curricula exists for how to use simulation for training in a structured way. The application in case 2 – practicing the use of medical technology in the context of critical care – is but one example of many possible ones.

The training tool in case 2 is with its interactive scenarios game-based in its design, hence relating to the concept of s*erious games*. This concept implies that games traditionally used for entertainment can be used for training and education, and even though research on this is just beginning to appear, there are indications that the motivational factors and the ability to design games for certain purposes is beneficial for learning (Johannes & Gary, 2010; Van Eck, 2006). Serious games have started to be used a lot in healthcare to motivate patients to learn about and take care of their own health issues. But they have also been highlighted as tools for training healthcare professionals (Howell, 2005) where case-based simulations that replicate real-life scenarios (as the one in case 2) are mentioned as one branch in this development. The concepts of gaming and simulation overlap to some extent and it is not always easy to distinguish between the two. The ability to incorporate elements of reality and set the activities in a context by telling a story around the situation is one main benefit of the gaming and simulation approach to learning. Moreover, this way of learning may appeal to a wider user group who have been excluded due to culture or language barriers, numeracy or literacy difficulties or disengagement from traditional teaching and learning methods (de Freitas, Savill-Smith, & Attewell, 2006). Something that was also pointed out as being important by the practitioners in case 2.

The trend of using simulation and games for training and education will most likely continue to evolve, encouraged by the ongoing discussion about *digital natives*, which refers to people who are "native speakers" of the digital language of computers, video games and the Internet and have been using computers and games since early childhood (Prensky, 2001). The point is that through the digital technology that we have around us today, both at work and in our private lives, the access to educational applications could be much higher. As a complement to simulations offered at a specific simulation center that require many resources in terms of time and people for a clinical department to utilize them, the training tools can be made available in the local setting and when staff have time to use them. We have seen a continuous development of smartphones and tablet applications of which ones related to healthcare training are increasing (Mosa, Yoo, & Sheets, 2012; Ventola, 2014). The attitude towards using this technology for training is transforming the culture and communication among students in medical training, where these devices offer a “learn anywhere” resource for accessing information or double-checking knowledge (Wallace, Clark, & White, 2012). Some believe that this trend will follow into the clinical environments, making smartphones and tablets ubiquitous in healthcare practice, and will change how professionals do their work and how they access material for training. A full-scale team simulation, of course, will not fit into a mobile device in the same form as a simulator center can provide, but a range of other simulations, complementing and enhancing traditional textbook presentations can be offered through these devices. How the devices will be used for healthcare training remains to be seen, but it is certainly an area of development that will gain more attention and require further research.

Visualization and simulation technology for planning

Case 3 shows how a combination of visualization and simulation technologies can be useful to involve staff and guide the process of planning new facilities for a clinic. By means of these methods practical information about facility proposals from the architect were presented in various ways and made available to the practitioners who, from a planning point of view, are laymen, while they are experts when it comes to their work setting. Much of this work-related knowledge is tacit and difficult to formulate in a list of requirements. By being able to experience a facility proposal through a simulated environment, the practitioners were able to better understand the proposal, express their knowledge and needs, contribute to the design, and develop an understanding for the planning process itself. The visualization and simulation technology thus served as a tool for eliciting knowledge and creating ways to communicate important and relevant information between different stakeholders in the process.

A special approach in case 3 was the *combination* of visualization and simulation technologies that was applied. There are studies that conclude that using traditional tools, such as pencil-and-paper sketches, in combination with other tools, such as virtual reality applications, is beneficial in helping the participants formulate, analyze and test ideas (e.g., Al-Kodmany, 2001; Fröst & Warren, 2000). Mathematical model simulation is usually used as a stand-alone tool while it has a potential to be an important complement in a more comprehensive suite of simulation tools for planning. Using a combination of visualization and simulation technologies in the process helped to present information in alternative ways and elicit questions from different perspectives, thereby enriching the output of the process. A concrete example of this is reported in case 3 related to single and double bedrooms. The room type distribution and its effect on the layout could be studied in the 3D or virtual full-scale models, while the interior design could be experimented with in the physical full-scale models. The discrete event simulation provided knowledge about patient throughput and waiting times as well. Different technologies, moreover, appeal differently to participants and stakeholders. We could see in the study that the tangible full-scale model was easier to interact with for the practitioners than the virtual full-scale model in which they felt a bit uncomfortable due to their lack of experience in using that type of technology. On the other hand, the discrete event simulations that generated quantitative output were welcomed by hospital managers and people in the hospital planning team. This was probably because they provided them with quantitative measures that are thought of as being more objective than the outcomes from the workshop with full-scale models and are hence easier to use in prioritizing. A risk of putting too much trust into the numbers from the discrete event simulation is that the users are not aware of the limitations of this model. To draw conclusions, one needs to keep in mind that the results are based on a simplified model of reality. The simplifications and assumptions that are made in the model and the data entered into the simulation are fundamental for the validity of the results. The simulation itself does not provide any qualitative information of what the problem is when a bottleneck or something similar is found in the system. But by identifying possible problems one can further investigate these areas with other methods already at the planning stage to prevent the implementation of bad solutions.

As a consequence of the first round of visualization in case 3 that extended the 2D blueprint into a simple 3D model displayed on a standard computer, the facility proposal was discarded due to problems identified, mainly in the entrance area. This could be an argument against adopting a participatory design process since the proposal presented may change one or several times during the process, implying that design decisions will quickly become obsolete. On the contrary, we could see that much of the information that was discussed and revealed in the process was on such a general level that it was relevant for both current and future proposals, while not losing contact with the local context.

Fidelity in visualization and simulation

It is important to discuss how the fidelity component influences the application. In the planning process of case 3 we could see that the models certainly triggered discussions and that the level of detail in the models seemed to be sufficient. The participants did not get stuck on non-relevant details, nor did they have difficulties in setting themselves in the context and explore the models as if they were in their own work environment. Similar behavior could be seen in case 2, where the users were engaged in the low-fidelity representation of the patient and that all information was interpreted correctly despite variations in the level of fidelity in the prototype.

We observed that all practitioners had a great capability to mentally fill in missing information in the models. They knew so much about their work setting that even though a lot of information was omitted, they "decorated" the models with this knowledge. Sometimes it came to light that various people had different mental models and hence disagreed on something, while in other situations it was fascinating to see how much they could do from very basic visual feedback by filling in information themselves. This means that for this specific user group, the virtual or full-scale models can be generated with a lower level of detail since the practitioners are experts in their domain and thus have the necessary mental models to fill in information themselves. If on the other hand the participants had been a group of patients, the model used would probably have not been enough since they do not possess the same amount of knowledge about the environment.

Thus, the level of fidelity of the model must be adapted to the users and where in the process it is used. The same reasoning goes for a simulation tool that is developed for training. A more experienced practitioner would not need as much information explicitly presented to make sense of the simulation – it might even be disturbing – while a novice user might need an increased fidelity to optimize his/her learning. One specific feature that illustrated this difference well in case 2 was the audial input used in the prototype. The alarm signals and sounds from the patient are central for how to interpret and act in a specific situation. More experienced nurses reported that they could filter among the sounds and use them to guide their actions, while two novice assistant nurses were extremely stressed by the sounds and gave no impression of being able to sort among the various sounds. In this case the sound feedback should not be removed for the more experienced nurses, but handled in different ways in the tool. Since sound interpretation was found to be such a central source of information, one could add learning objectives related to this for novice users so they could increase their knowledge in this area through the simulator system.

The level of fidelity must be considered for each situation and context in order to fit the purpose of the application. By adopting a human-centered approach, this consideration becomes a natural part of the process as compared to a technology-centered one where the technical solution is all too often set before obtaining thorough knowledge about the users, task and context.

From technology-centered to human-centered

The second aim of the thesis is to put forward a discussion about a technology-centered versus a human-centered approach in the design and development process of visualization and simulation technology. In my licentiate and doctorate research I have been involved in projects representing both a distinct technology-centered perspective focused on the *technical advancement* of the system, and a human-centered perspective focused on the *application* of the visualization and simulation technology. This has given me a broad understanding of how large the gaps between different domains (different work groups, different knowledge domains, different research disciplines, etc.) can be and the complexity in bridging these gaps. The review in Paper IV is a reaction to this development and provides a reflection upon the extent to which the human-centered perspective is prevalent in publications about simulator systems for training in healthcare. The low number of publications describing the design and development process, and reflecting upon the methods used in this process, indicates that this perspective is not generally considered in this community. Instead, a technology-centered perspective dominates, both as a way of working and the way studies are presented. Compared to the development of other digital systems in healthcare, such as administrative IT systems, where a human-centered design and development methodology is more common, the area of visualization and simulation technology for training has not yet adopted this way of working.

Case 1 represents a technology-driven project in which underlying algorithms and technical implementation of the simulator system was developed and enhanced without the principles of human-centered design being fulfilled (no thorough investigation of the users, tasks and environments was done; the development was to some extent iterative but did not include a user-centered evaluation in the process; and no team of professionals with multidisciplinary skills and perspectives was involved). This does not by default mean that the work in this study is not motivated. The application is certainly useful for training and planning of hip fracture surgery. It would have been interesting to set this strict technical development in a human-centered framework to ensure the application in the end correlated to the needs and requirements of the users. A more human-centered approach has lately been acknowledged in some international projects in which the principles of human-centered design are adopted or further investigated for developing technology for surgery training or surgical support (Freudenthal, Stüdeli, Lamata, & Samset, 2011; Lövquist, Shorten, & Aboulafia, 2012). However, it is not obvious even in these studies that an actual need for the system was identified, even though a human-centered design process was conducted during the development.

The empirical studies presented in case 2 and 3 apply a more human-centered approach by employing users as active participants in the process; by developing knowledge about the users, tasks and the environment throughout the process; by involving people from different disciplines in the project team; and by creating design solutions iteratively influenced by user-centered feedback. Exactly how to implement the human-centered approach needs to be reflected upon for each individual process in order to create an approach with methods and resources adapted to the specific project. The difference from the approach in case 1 is that the problems addressed in case 2 and case 3 were anchored in the clinical context and existing in a complex reality – a reality that was taken into account in the subsequent process.

A human-centered approach is about having a holistic view, where the interaction between end users, stakeholders, tasks, use context, organization and implementation are all key components. This is something that is often neglected in a design process that treats the user as an isolated individual interacting with the system (Gasson, 2003). This is in line with the reasoning of Bannon (2011, p.53) who states that a human-centered perspective means "more than simply 'considering the user' in technology development. Rather it places our understanding of people, their concerns, and their activities at the forefront in the design of new technology." If we return to the culture and preconceptions that exist in engineering and engineering education, we can generalize and say that an engineer is trained in solving isolated problems following objective guidelines and principles; this does not include seeing the problem as part of a larger and very complex whole. To bridge this culture to a human-centered approach, documents like the ISO standard, *ISO 9241-210:2010 Ergonomics of human-system interaction -- Part 210: Human-centered design for interactive systems (ISO 9241-210, 2010)* fills a purpose. Through this type of guidelines, a community that is not used to this way of thinking can obtain a "checklist" to follow in order to steer the process in the human-centered direction. In this sense, the document can be seen as being objective and as providing tools and techniques for working human-centered, which could appeal to the engineering community. One might wonder to what extent the approach presented in the ISO standard (or similar documents) is human-centered, how easily it is applied in practice and what effect it has on the outcome of the design process. Is it enough to follow these guidelines in order to work human-centered? Are there any other qualities or a certain mind-set that is needed in this process to be able to actually work human-centered?

These questions may also lead to asking one fundamental question about working human-centered: Why is a human-centered perspective preferred to the traditional technology-centered way of working? From my empirical studies of simulation for training I cannot say that the training system developed in a more human-centered process (case 2) would increase the learning outcome compared to the other (case 1), since the two systems are not used in practice and since it is not possible to compare learning in that way. I can however state that based on the participatory approach of the application for medical technology in the context of critical care (case 2), the technical solution and the learning objectives were adapted to and situated in the local context and hence highly relevant for the professional education of the staff at that clinic. It additionally contributed to increased learning about both individual and organizational aspects for the people involved in the participatory design process. They had to reflect upon their work, decompose situations into detailed descriptions and formulate ideas for how to share knowledge about them among the staff. Using the tool triggered these discussions even further since the users did not always agree upon one correct answer, meaning that the construction of knowledge could reach beyond the specific occasion in which the tool was used, by means of group discussions, for example.

Implications for practice

To just state that visualization and simulation technology has much to offer in healthcare if applied correctly is not of much use without ideas and suggestions for its practical implementation. The specific characteristics of the context must be taken into consideration such as purchasing regulations, inter-professional structures, and the work organization. I will summarize my thoughts on this with a number of concrete implications for how to apply visualization and simulation technology for sharing information and knowledge and to support training, planning and participation in the healthcare context.

Use available infrastructure and accessible technology

One could object to the usage of some of the methods adopted in these empirical studies. Take the full-scale virtual models for example. Hospitals do not have a virtual reality lab available or in-house competence to create 3D models or develop computer simulations for training. Training centers exist where certain simulation systems are available, but not all clinics have the resources to send people there. As an alternative to a virtual reality or full-scale lab, or as a complement to the training at centers, infrastructure already available such as desktop PCs, screens and projectors, tablets, etc., would need to be utilized more and the visualization and simulation technology needs to be made accessible in the local setting of the clinic. This has two implications: 1) that the technical solutions are already in place and no extra investments need to be made, and 2) that the visualization or simulation technology is presented by means of technical solutions that the practitioners are already comfortable using. No special training or adjustments on their part are required.

Most PCs are powerful enough to run advanced computer-based 3D models or mathematical simulations and no special equipment is needed for. A computer-based simulation for training or a 3D model of a new facility proposal can be managed by most of the computers available in a hospital clinic. A full-scale perspective can be obtained as well by means of large screens and projectors, although not with the same level of immersion as can be found in a fully enclosing environment, but sufficient to share information in alternative ways and engage people in the discussions. And in reference to the earlier discussion about fidelity, and the importance of adjusting the technology to the needs of the humans, the tasks and the context, it is reasonable to adapt the visualization or simulation so that it can be used in the local clinic setting rather than in an external training center even if this implies a lower – or at least altered – level of fidelity.

Roles and competencies

Even if the technology is available in a clinic with the existing infrastructure, the competence needed to create the visualization or simulation still needs to be considered. It is not feasible to expect the practitioners in a clinic to have the skills and time to do this. A facilitator is also needed to coordinate the activities in a planning or development process; someone with the knowledge to determine the relevant methods to use, engage stakeholders, collect data and compile it into something useful.

This is important when external partners are involved, such as architects and system developers, where the exchange of internal and external knowledge is central. As previously pointed out, the internal knowledge (within the hospital organization) is disparate, involving different professions, different clinical disciplines, management, etc. Due to the organization of a hospital and the regulations for purchasing, it is not often that the end users are the ones that have direct contact with the external partners; instead there are other centralized parts of the organization that handle the communication and set the requirements. The same goes for the external parties. It is not often that the system developers are in contact with the end users or the end use context. The communication passes through some other employee in the company, such as a product manager. This means that to work participatory in any process, organizational structures must exist higher up in the hospital that support this as well as external partners that promote this way of working. Each individual clinic does not have the authority, power or incentive to do so.

To be able to spread generated knowledge and experience it is crucial to be able to involve stakeholders from many domains and levels in the organization and have an organization that supports this way of working more strategically, not only as a small isolated process (Simonsen & Robertson, 2013, p.131). For the project behind the empirical research in case 2 and case 3, *Computer-aided Visualization for Learning, Participation, Planning and Change in Advanced Healthcare*, a work process was chosen to augment the potential for the results of each subproject to have an influence outside the local context. A network of actors was formed to create a basis for the exchange of knowledge and mutual learning. The core team in this project consisted of researchers from the Department of Design Sciences, staff from the two different hospital clinics represented in case 2 and case 3 and one representative from the county council. Even though these studies have mainly been discussed individually in the thesis they were both part of this larger context formed by the project. This opens up for the participants to gain a broader understanding of alternative ways of working in different clinical disciplines, as well as setting their local issues in a larger context and viewing them with new and wider perspectives.

Due to the high level of reorganization and demands on increasing efficiency from healthcare, it would be worthwhile to further investigate which central functions or local initiatives could be added to support a more design-based and participatory way of working in general (not only with visualization and simulation technology) and study what this adds to the organization.

Generic and specific skills

The purpose of the *Computer-aided Visualization for Learning, Participation, Planning and Change in Advanced Healthcare* project behind cases 2 and 3 was to generate knowledge beyond the specific activities performed in each case by sharing experiences in the whole project team and distributing this knowledge to colleagues in the organization or nationally in conferences, meetings, forums, etc. The knowledge in focus here is of a generic character and relates to skills that can be applied outside a specific situation, such as problem-solving, communication, and the ability to reflect upon actions (as opposed to specific skills that are valid in a specific context, such as certain surgical procedures). In the research project we could see that working in this way in clinical practice had a positive effect on engaging the practitioners, encouraging mutual learning, sharing experiences and stimulating alternative ways of thinking about one's work organization.

On another level, one can also say that the knowledge generated from using the simulator in case 1 is dedicated to the training of specific skills related to a specific surgical procedure, while the knowledge generated from using the simulation in case 2 is focused on generic skills since it explicitly concentrates on decision-making and supports communication about critical situations. Finding the right learning objectives for a training tool, and being aware that generic skills can also be trained by means of visualization and simulation technology, are valuable conclusions from cases 1 and 2.

A lot of data – what to do with it all?

One area where visualization and simulation technology can play an increased role is to learn from data about the organization that is collected for various purposes. All clinics and work units gather a considerable amount of statistics, such as time related to patients coming or going, patient throughput, work hours and room utilization. In this data there is a huge amount of information that can be used to find patterns of work routines and patient activities and to improve the organization. In case 3 this type of data was used mainly for discrete event simulation to study room utilization and patient throughput. Although the data was available, it was not straightforward how to use it. Manual editing and extra data collection was required. Discrete event simulations, or similar mathematical-based computer simulations are commonly used for decision-making in hospital and healthcare development (Gibson, 2007; Jacobson et al., 2013; Medeiros, Swenson, & DeFlitch, 2008; Sobolev, Sanchez, & Vasilakis, 2011). Besides mathematical modelling simulation the data gathered are mainly analyzed and visualized through traditional bar or pie charts. By extending the ways of visualizing and analyzing various data additional and more useful knowledge could be provided to support decision-making, design flexible systems, investigate future needs and evaluate possible solutions (Hahn & Zimmermann, 2011; Kelsick, Vance, Buhr, & Moller, 2003). To utilize this potential in applying visualization and simulation technology to this data efforts need to be put into studying what data to collect and in what format.

Methodological considerations

This thesis spans a broad area of research methods, ranging from the development of algorithms and the technology "under the hood" for surgery simulation, to participatory design of education tools and facilities, to methodological considerations of working human-centered contra technology-centered in the application of visualization and simulation technology. From a personal point of view this has been an interesting journey from a research culture in which the term "method" basically referred to choice of mathematical algorithm or the evaluation method chosen to verify the mathematical model, to a research culture that is truly multidisciplinary in the sense that methods from several research areas – engineering, natural sciences, social sciences, etc. – are intertwined. From not being familiar with the term "qualitative method" to having to dive into this diverse field of methods and try to choose the optimal combination for my own research purposes has been a challenge. This has of course had an effect on the methods selected, the data analysis, and the way this is presented in the appended papers and the thesis. With an engineering background, working in the field of HF/E and HCI towards applications in healthcare, there are several angles one could take when presenting the studies and addressing the readers. Results can be of interest to various communities if the angle of analysis is adjusted. My intent has been to present the results in relation to the healthcare community, since the aim has been to apply the methods and tools in practice, while development of new technology was secondary in the recent studies (as compared to the work in case 1, where the simulator system itself was new as well as the methods for creating the virtual hip models). To a certain extent I also turn to the community of system development which often has a technology-centered perspective. For them I will let a quote from an article by Stone & McCloy (2004) summarize my thoughts on this:

> We describe the growing relevance of ergonomics or human factors principles and methodologies to medical and surgical practice, emphasizing the importance of moving away from "technology push" (the assumption that a high tech approach to the design of information technology systems will always provide a robust, reliable solution) to one that is more focused on the needs of the human in the design of medical equipment, systems, and processes.

I would like to turn this "divergence" of my research background into something positive, emphasizing the importance of having seen several sides of the process and knowing that one side is not always more legitimate than the other. Instead they complement each other and having people with different competencies, who are open-minded to each other's knowledge and who see the potential in mutual learning is valuable. I have gained insight into the fact that it is not straightforward to move toward a participatory and human-centered way of working when coming from a field that has a technology-centered perspective. This is something I will bring with me both in future research studies as well as in engineering teaching activities.

Quality assessment of the research

Reliability and validity are two central terms for assessing the quality of the research conducted. Reliability is highly related to replicability and refers to a presentation of the research in such a way that the results may be reproduced by someone else in another setting, using the description provided in a study. In positivistic research, based on quantitative research methods, this is considered relevant and more easily accomplished. In research based on qualitative methods, the term "reliability" is more debated. The qualitative nature of the research means that the social context, the people involved and the role of the researcher influence the outcome so that the replication of the research situation is not possible (Denscombe, 2009, p. 379). By making the research process transparent by thoroughly describing the research and analysis methods, and clearly stating the theoretical context in which the studies have been performed, the reliability criteria may also be met for qualitative research methods (Silverman, 2006, p. 282).

Validity is related to how well the selected methods actually provide information about the questions of interest. It is relevant to motivate the methods selected and how they contribute to the findings. Combining methods is a matter of balancing between ones that are relevant for the research questions and that can be triangulated. Too many methods or methods that are irrelevant for data collection should not be used. Otherwise, one risks ending up with such a variety of data from the different methods that the analysis moves the focus away from the specific research question (Silverman, 2006, p. 9).

The concepts of reliability and validity are met here by providing thorough descriptions of the whole research process in order to give a transparent view of the context of the studies performed, the activities in the research process, the methods selected, the process of analysis and the theoretical setting.

The generalizability of case studies must be considered as well since it is not straightforward how and if they can be generalized (Denscombe, 2009, pp. 68-70). One must be careful about making too far-reaching claims based on the data analysis. Careful considerations about the choice of data gathering methods guided by the research questions, and transparent descriptions of the data analysis help to increase the research validity and to support generalization attempts. This is easier said than done. At the beginning of the study it may not be clear what the research questions are or they may change during the process. The setting in which the study takes place may not have been chosen exclusively for the purpose and the complexity of working in a real environment will without doubt affect the progress of the study. In healthcare this is highly visible when it comes to practical issues such as access to the practitioners who are engaged. They can be interrupted by other duties or are at times impossible to get hold of. There are also the ethical considerations to address when making observations in a hospital clinic in term of how patients are affected, or how evaluating prototypes, for example, can change the daily work routine.

With this in mind I would like to comment on the results and conclusions that are presented in this thesis. Due to the disparity of the studies and the expanded time period during which they have been conducted, I would like to elaborate upon the direction of the scientific approach that the research finally took.

The common features of the two earlier studies (Papers Ia-Ib) and the three later ones (Papers II-IV) are the interest for visualization and simulation technology and its application in the healthcare context. At the time of execution the earlier studies focused on the function of the segmentation algorithms for the hip surgery system. In the context of this thesis, however, I have chosen to study them with a more process-oriented perspective to understand how the development process shaped the resulting system. This enabled me to take an overall perspective of the technology-centered versus human-centered approaches of technology development and use by allowing me to see this from various positions on a continuum between these two extremes. From this point of view I want to emphasize that the empirical studies constitute a set of examples for how visualization and simulation technology can be a useful tool for training, planning and participation in healthcare. This set of examples may not be formally generalizable but can contribute to the cumulative development of knowledge in the research field (Flyvbjerg, 2006). Extensive generalization is not per default the goal in all research. Yin (2014, pp. 40-41), furthermore, highlights that the traditional way of generalization by making an inference about a population based on a sample of this population, known as *statistical generalization*, is different from the way one generalizes from a case study. In the latter, the cases are not to be seen as sampling units because they would be too few to serve as a foundation for a statistical generalization. Instead an *analytic generalization* should be made, with the implication of generating knowledge that "goes beyond the setting for the specific case that was studied" and linking the findings to a theory.

As described in the data analysis section, case 1 did not involve a qualitative analysis of data due to the mathematical nature of the study. As pointed out, though, there was a certain aspect of subjectivity involved since no comparison of the segmentation results were made to corresponding results using other algorithms or a manual segmentation process. What would have been needed in this study to increase trustworthiness was to perform at least one of these comparisons to be able to make a more general conclusion of the performance of the developed algorithm. In other ways subjectivity was not an issue, which may have been the case if the value and usefulness of the simulation system itself had been evaluated.

For the qualitative analyses in cases 2 and 3, a number of methods for data collection were used and I cannot state for certain that the optimal ones were selected and the extent to which the choice influenced the analysis and results. The methods can be well motivated based on their purpose in the data collection process, and by gathering data with multiple methods the validity was strengthened since the results can be more firmly grounded in data and the risk for subjective interpretations is reduced (Lazar et al., 2010, p. 295). In the analysis process, a continuous exchange and discussion about the content with the co-authors has guided the analysis and conclusions, even if no explicit coding of the content was carried out by others than myself, making it impossible to express the reliability of the analysis in terms of inter- or intra-coder reliability (Lazar et al., 2010, p. 296).

Another aspect that you struggle with when writing a thesis is the choice of theoretical glasses through which the research should be viewed. Even though there are some natural points of departure for approaching the work that emanate from the background of the researcher and the discipline in which the studies are conducted, there is also considerable room for options; the more you work with your thesis and the deeper you dig into your material, the more theoretical perspectives and ideas you gain for approaching it. The chapters on Theoretical context, Summary of appended papers and Discussion are where the perspectives selected are clarified. There are certainly other views that could have been interesting to use, and other discussions that would have been relevant, but somewhere along the line you need to settle on a reasonable and relevant set of ideas to emanate from, and these are the one that you find here.

Conclusions

This thesis shows how visualization and simulation technology supports training, planning and participation in the healthcare context. Three cases present new or expanded areas of application for this technology. The areas of application are demonstrated with examples that include the training of specific skills and pre-operative planning of hip surgery (case 1), the training of generic skills for medical technology in critical care (case 2), and the involvement of staff in planning their own work organization (case 3).

The methods used for developing the training systems in cases 1 and 2 contrast in their approach: Case 1 was developed with a traditional technology-centered approach and case 2 was with a more human-centered approach. The research field is vast when it comes to technical or engineering perspectives on developing visualization and simulation technology. There is also considerable research related to methods for participation and user involvement in the fields of human factors and human-computer interaction. In the intersection of these two areas, new knowledge about visualization and simulation technology as a tool for human-centered development and applications can be generated. Learning more about this is relevant because of the increasing use of visualization and simulation technology that is encouraged by the need for innovative ways of working with education and organization development in general.

Healthcare is a setting that needs to adapt to an increased used of technical solutions due to the challenges it faces. It needs to find new ways of organizing work to manage an increased number of patients and to provide a sustainable and attractive work environment for its employees. Visualization and simulation technology can be one tool that is used in this process for adopting new ways of training, planning future work environments and organizations, and making the practitioners active partners in this development.

The studies presented in the appended papers and the discussion chapter offer additional insights gained about the potential of visualization and simulation technology from theoretical perspectives and with practical implications for healthcare practice. The emphasis is on how technology-centered versus human-centered perspectives influence the design and development process and the communication among the involved stakeholders.

The following list is a summary of the main conclusions of this thesis:

- There is a high potential for using visualization- and simulation-based applications in healthcare as a tool for training, planning and participation. New and relevant areas of application may be found quite easily. The obstacles that exist from traditional ways of working in the healthcare sector must be overcome to be able to test these applications in practice.
- Visualization and simulation technology for healthcare training is currently developed with a primarily technology-centered perspective. Turning this towards a human-centered perspective would create applications that are better anchored in the users' needs, tasks and context.
- The level of fidelity must be considered for each individual application. The users' pre-understanding of the content and the use context must be well understood to find a suitable level of fidelity. When visualization and simulation technology is used in a design process, the level of fidelity is highly related to where in the process the technology is being used.
- The visualization and simulation technology still "belongs" to the technical community and to be used, someone with technical expertise is needed in the process. To try to alter this imbalance, it is important to promote a human-centered approach in engineering education, and to facilitate learning about methods from design research that are useful in this process. This is one way forward towards increasing the chances of working more human-centered in all types of technical development.

Further research

All the research questions raised have resulted in a number of new ones. I have already started to work on new projects relating to healthcare in the development of home care. Meanwhile, many questions and ideas remain for future investigation.

One direct idea emanating from case 2 is the use of alternative methods for training and education in healthcare. The area of medical devices is of special interest since new technology and new models of existing devices are constantly being introduced. Not many studies have examined continuing education for practitioners in the use of medical technology (Brand, 2012). In a smaller study from 2001, performed in the UK, the authors found that the dominant source for learning was still to read product literature and product manuals, suggesting that there is room for novel educational strategies (Douglas, Leigh, & Douglas, 2001). It is an area that can be studied with an organizational perspective since the introduction of new or improved technology may alter the roles of the practitioners. What was once performed by a doctor may with altered medical technology be delegated to a nurse, which changes the relations between professions as well as the interaction with the patient. With care moving into the home to a greater extent, and with more people living with one or several diseases, the use of medical technology outside the hospital is increasing. This puts demands on technology that can be used and learned by patients themselves, relatives, assistant home care nurses, etc., opening the door to even more challenges related to the education and use of medical devices.

One driving force in the development of home care is the application of e-health. E-health is a field under development but can be broadly defined as "an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies" (Eysenbach, 2001). It is thus related to more than the introduction of technical solutions to streamline healthcare but nevertheless focuses on the fact that people will to a larger extent handle different medical devices and perform measurements or handle medication without the direct assistance of healthcare personnel. This places higher usability demands on devices, and systems that many people are able to learn, despite their background, language and educational level, and with no medical knowledge. For this purpose visualization and simulation technology can be a useful tool for learning (de Freitas et al., 2006). The introduction of e-health systems will change the organization of how healthcare is provided, which requires new ways of thinking about how care is provided. In this reorganization, visualization and simulation technology can simulate various scenarios, communicate information and let various user groups contribute to the development.

Even though this thesis has promoted a human-centered approach where the choice of technology should not be the driving force, it is relevant to keep up to date on technical developments of visualization and simulation technology to understand if there are new tools and methods that can be useful. The amount of digital technology that we surround ourselves with (smartphones, tablets, smart bands, etc.) has transformed our attitudes towards the way we receive and discover information. Another area where developments have moved forward is the technology of various kinds of head-mounted display. Some years ago this referred to rather big, heavy equipment but now it is smaller and lighter and can more easily be used while moving around. With head-mounted displays and augmented reality[3] training can be moved directly into a setting by viewing the real world while projecting virtual information on top of it. For medical devices it can be used to get support for handling a device that is new to the user, to learn the functions, and to get remote help from experts. For planning processes, this technology may be useful for simulating new environments in which the user can move around before they have been built, or for augmenting ideas for rebuilding on top of the real environment to inform and involve participants in the design process.

[3] *Augmented reality* refers to the technology of combining real and virtual objects. Augmented reality supplements the real world (compared to virtual reality, which is a completely synthetic reality) and offers the user methods to interact with it (Azuma, 1997).

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