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PARTICIPATORY SIMULATION IN HOSPITAL WORK SYSTEM DESIGN

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Technical University of Denmark
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Participatory simulation in hospital work system design

PhD thesis

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ACKNOWLEDGMENTS

My curiosity in and interest for ergonomics and participatory simulation began during my education as a design engineer at the Technical University of Denmark (DTU) and my student employment in a Danish work environment consultancy. When I had the opportunity to study these topics for this PhD, my curiosity and interest developed into motivation.

This study turned out to be a true adventure for me. As in all adventures, there have been ups and downs. My boundaries have been pushed and my skills have been challenged, resulting in a process of professional development as well as personal development. Several people have supported and shared this adventure with me.

My supervisor, Ole Broberg, motivated my interest in ergonomics and participatory simulation during my engineering education. Thank you for being an inspiration and for your great tolerance when I occasionally fumbled in the learning process of the study. Thank you for believing in me and for pushing me "out into open water." Furthermore, thank you to my co-supervisor, Erling Havn, for your wise perspectives, which always got me back on track.

Thank you to the researchers at the Center for Quality & Productivity Improvement at the University of Wisconsin-Madison, USA, for valuable feedback and for challenging me during my research stay. Furthermore, I would like to thank the simulation facilitators, health care professionals, and designers involved in the cases of the study. I appreciated your engagement and I truly learned from your many experiences.

A great thank you to my colleagues in the Engineering Systems Division at DTU for spot-on critiques and for your way of letting me into a unique community. A special thank you to my dear officemate, Carolina Conceição, for patting me on the shoulder in my "downs" and for laughing with me in my "ups." Additionally, thank you to my former colleague, Liv Gish, for being a great support in the final writing phase.

A final thank you to my friends and family for all your love and support; and to Peter for being my best friend and the world's most patient and caring husband.

Simone Nyholm Andersen, Kgs. Lyngby, Denmark, September 2016.

SUMMARY

When ergonomic considerations are integrated into the design of work systems, both overall system performance and employee well-being improve. A central part of integrating ergonomics in work system design is to benefit from employees' knowledge of existing work systems. Participatory simulation (PS) is a method to access employee knowledge; namely employees are involved in the simulation and design of their own future work systems through the exploration of models representing work system designs. However, only a few studies have investigated PS and the elements of the method. Yet understanding the elements is essential when analyzing and planning PS in research and practice.

This PhD study investigates PS and the method elements in the context of the Danish hospital sector, where PS is applied in the renewal and design of public hospitals and the work systems within the hospitals. The investigation was guided by three research questions focusing on: 1) the influence of simulation media on ergonomic evaluation in PS, 2) the creation of ergonomic knowledge in PS, and 3) the transfer and integration of the ergonomic knowledge into work system design.The investigation was based on three PS cases in the Danish hospital sector. The cases were analyzed from an ergonomics system perspective combined with theories on knowledge creation, transfer, and integration. The results are presented in six scientific papers from which three core findings are extracted: 1) simulation media attributes influence the type of ergonomic conditions that can be evaluated in PS, 2) sequences and overlaps of knowledge creation activities are sources of ergonomic knowledge creation in PS, and 3) intermediaries are means of knowledge transfer, and interpretation and transformation are means of knowledge integration.

This study contributes in two ways to the limited knowledge base on PS in the ergonomics field. First, this study synthesizes its findings into a PS taxonomy that provides an overview of the elements constituting the PS method. The PS taxonomy provides a frame for analyzing and planning PS in both research and practice. Second, this study reveals how the PS elements affect PS outcome and the impact of the outcome on work system design. This study concludes that PS is a highly potential method for ergonomic work system design, but the different PS elements must be carefully and deliberately planned and facilitated to harness this potential and to achieve an actual design impact.

DANSK SAMMENFATNING

Undersøgelser har vist at medarbejdernes trivsel og effektivitet øges når arbejdsmiljøovervejelser integreres allerede i designfasen af arbejdssystemer. En central del af denne arbejdsmiljøintegration er bundet op på ideen om at drage nytte af medarbejdernes viden om det allerede eksisterende arbejdssystem. Brugerdreven simulation (BS) er netop sådan en metode til at tilgå medarbejdernes viden. I BS involveres medarbejderne i simulation og design af deres eget fremtidige arbejdssystem. Modeller af det fremtidige arbejdssystem udforskes og afprøves igennem simulation udført af medarbejderne. Kendskab til elementerne der indgår i BS metoden er vigtigt når BS skal analyseres eller planlægges, men kun få videnskabelige studier har undersøgt disse. Derfor undersøger dette ph.d.-stude BS og de elementer som indgår heri.

Studiet er baseret på den danske hospitalssektor hvor BS benyttes i renoveringen og designet af de nye super-hospitaler samt de arbejdssystemer som indgår i hospitalerne. Udgangspunktet for studiet var tre forskningsspørgsmål som fokuserede på 1) simulationsmediernes indflydelse på arbejdsmiljøevalueringer i BS, 2) skabelsen af arbejdsmiljøviden i BS og 3) overførslen og integrationen af denne viden i arbejdssystemdesign. Forskningsspørgsmålene blev undersøgt gennem tre cases med BS i den danske hospitalssektor. Resultaterne af undersøgelsen er præsenteret i seks videnskabelige artikler hvoraf tre hoveresultater er fremhævet her: 1) simulationsmediets egenskaber påvirker hvilke arbejdsmiljøforhold som kan vurderes ved hjælp af BS, 2) kilden til videnskabelse i BS er sekvenser og overlap af videnskabende aktiviteter, og 3) midlerne til videnoverførsel er aktører og objekter som agerer mellemled mellem BS og designprocesser, og midlerne til videnintegration i arbejdsmiljødesign er tolkning og omformning af den overførte viden.

Ph.d.-studie bidrager på to måder til den begrænsede eksisterende forskning indenfor BS. For det første bidrager studiet med en BS taksonomi som er en syntese af resultaterne fra studiet og giver et overblik over de elementer som indgår i BS. For det andet afslører studiet hvorledes elementerne påvirker de resultater som kommer ud af BS. Studiet afslutter med at konkludere at BS er en metoden med potentiale for at drage nytte af medarbejderes viden i design af arbejdssystemer. Dog argumenterer studiet også at elementerne i metoden nøje skal planlægges og faciliteres for at drage nytte af dette potentiale og dermed rent faktisk opnå en indflydelse på designet af arbejdssystemer.

DISSEMINATION OF THE PHD STUDY

As a part of this PhD study, I have disseminated my work in the form of research papers and presentations at scientific and professional conferences. The dissemination is listed below.

RESEARCH PAPERS

Andersen, S. N., & Broberg, O., 2016. A framework of knowledge creation processes in participatory simulation of hospital work systems. *Ergonomics* doi:10.1080/00140139.2016.1212999

Andersen, S. N., 2016. The process of participatory ergonomics simulation in hospital work system design. In *Proceedings of International Design Conference, Design*, pp.1825–1834

Andersen, S. N., & Broberg, O., 2015. Participatory ergonomics simulation of hospital work systems: the influence of simulation media on simulation outcome. *Applied Ergonomics*, 51, pp.331–342

Andersen, S. N., 2015. The role of knowledge objects in participatory ergonomics simulation. In *Proceedings 19th Triennial Congress of the IEA*.

Andersen, S.N., 2015. Rehearsing the future in healthcare work system design. In *I-PrACTISE annual meeting 2015* (Poster)

Andersen, S. N., & Broberg, O., 2014. Simulation in full-scale mock-ups: an ergonomics evaluation method? In O. Broberg et al., eds. *11th international symposium on human factors in Organisational Design And Management & 46th annual Nordic Ergonomics Society conference*. Copenhagen, pp. 793–798

Andersen, S.N., Broberg, O., (Under review), Ergonomics knowledge transfer from participatory simulation and integration into hospital design. In *Human Factors and Ergonomics in Manufacturing and Service Industries*

PRESENTATIONS AT SCIENTIFIC CONFERENCES

Andersen, S. N., 2016. The process of participatory ergonomics simulation in hospital work system design. At *International Design Conference, Design*, Dubrovnik, Croatia.

Andersen, S. N., 2015. The role of knowledge objects in participatory ergonomics simulation. At *19th Triennial Congress of the IEA*. Melbourne, Australia.

Andersen, S.N., 2015. Rehearsing the future in healthcare work system design. At: *I-PrACTISE annual meeting 2015*. Wisconsing, Madison, US.

Andersen, S. N., 2014. Simulation in full-scale mock-ups: an ergonomics evaluation method? At *11th international symposium on human factors in Organisational Design And Management & 46th annual Nordic Ergonomics Society conference*. Copenhagen, Denmark.

PRESENTATIONS AT PROFESSIONAL CONFERENCES

Andersen, S. N., 2016. Brugerdreven simulation (Participatory simulation), *Workshop for architects and ergonomic consultants at Rambøll*, Rambøll, Copenhagen. Denmark.

Andersen, S. N., 2016. Brugerdreven simulation: evaluering af taksonomi (Participatory simulation: evaluation of taxonomy), *Workshop for ergonomic consultants, architects and engineers*, DTU, Kgs. Lyngby. Denmark.

Andersen, S. N., 2016. Brugerdreven simulation i arbejdspladsdesign (Participatory simulation in workplace design), *Presentation at conference for safety managers established by "Industriens Uddannelser" ("The Educations of the Industry")*, Svendborg. Denmark.

Andersen, S. N., 2015. Brugerdreven simulation i arbejdspladsdesign (Participatory simulation in workplace design), *Presentation at seminar "gamification af arbejdsmiljøet – kan alt sættes på spil?" ("Gamification of the work environment") arranged by IDA Arbajedsmiljø (The Danish Society of Engineers)*, IDA, Copenhagen, Denmark.

Andersen, S. N, 2015. Simulation: et værktøj til arbejdsmiljørigtig design – hvornår og hvordan? (Simulation: a tool for ergonomic design – when and how?), *Workshop at "Arbejdsmiljøkonferencen" ("The Danish work environment conference")*, Nyborg, Denmark.

Andersen, S.N., 2014. Simulation: et nyt virkemiddel i den forebyggende arbejdsmiljøindsats (Simulation: a new instrument in preventive ergonomics), *Workshop at "Arbejdsmiljøkonferencen" ("The Danish work environment conference")*, Nyborg, Denmark.

Sperschneider, W., Broberg, O., Lippert, A. og Andersen, S.N., 2014. Brugerdreven simulation (Participatory simulation), *Workshop at "Region-*

hovedstadens innovationskonference" ("The innovation conference of the cap-*ital region"),* Copenhagen, Denmark.

Andersen, S.N., 2013. Simulation for designing new hospitals, *Presentation at "Internationalt netværksmøde med hospitalsplanlæggere fra Singapore og DNU Skejby" ("International network meeting between hospital planners from Singapore and DNU Skejby hospital in Denmark"),* Århus, Denmark.

ADVISORY GROUP

I had from the beginning initiated an advisory group based on relevant actors from health care innovation and ergonomics consultancy. During the study, I have facilitated five meetings within the advisory group

The group consisted of:

- Lars Tornvig, Director at ArbejdsmiljøCentreret Øst
- Werner Sperschneider, health care innovation consultant
- Marianne Storm, development consultant at BrancheArbejdsmiljøRådet
- Heidi Brønnum, leading charge nurse, Herlev and Gentofte Hospital

CONTENTS

1. INTRODUCTION

In this section, I introduce my PhD study by describing the background, the study focus and the three research questions that have guided the study. To give an impression of the empirical foundation, I briefly introduce the three cases of the study before I define the delimitations and the structure of the thesis.

1.1 PARTICIPATORY SIMULATION IN HOSPITAL WORK SYSTEM DESIGN

In a hall, chipboard walls, large foam blocks and a hospital bed are lined up. Several people are walking between the walls and blocks, pointing and discussing. The group consists of an orderly and a technical employee from the local hospital, an architect, an engineer, a project coordinator and an ergonomist. To these people, the walls and bricks are not chipboard and foam—they are a hallway of a bed ward at a new future hospital. The orderly grasps the hospital bed and starts pushing it down the hallway. He turns it around the corner and stops. Then he pulls the bed backwards, turning it with the intention of pushing it back down the hallway again. In the turn, the front wheels collide with a foam brick wall. The wall almost collapses. "A wall just crashed," the architect says and walks towards the wall and puts it in the right position again. "Was that because we made the corridor narrower?" the project coordinator asks, pointing at the opposite chipboard wall. The orderly and the technical employee nod. "If it’s going to be this width, I need space in that direction," the orderly says, pointing at a third wall. "What if we move that wall a little bit?" the ergonomist asks. "Let’s try," the architect says, and grasps the wall and moves it about half a meter. The orderly pulls out the bed again without colliding with any walls. "That definitely gave some room for the work practice of the orderlies," the engineer concluded.

This is an example of the phenomenon I have been studying for the last three years, called participatory simulation (PS). Simulation means to imitate a real-world system. PS means that employees are participating in imitation, exploration and design of their own future work system. In this example, hospital employees, hospital designers and an ergonomist imitate, explore and design the hallway of a new public hospital and therefore also the hallway work system of moving hospital beds, flow of health care employees, moving patients and storage of technology. The hospital is in the process of being designed, and therefore the hallway does not yet exist but is represented by the chipboard walls and foam blocks. The goal is to contribute to the hallway design in the new public hospital.

From 2008 to 2020, Danish hospitals are undergoing a comprehensive renewal process of renovating, extending and constructing new buildings. The goal is to improve efficiency, quality of care and ergonomic conditions for the health care employees. Studies of ergonomic conditions in the Danish hospital sector stress the need for this improvement. Compared to other sectors, Danish hospital employees have a significant higher tendency of burnouts, work within much poorer indoor climates, and are highly prone to physical disabilities (Lund 2013; Videncenter for arbejdsmiljø 2011). Since 2014, 20 out of 27 Danish hospitals have been rated by the Danish labor inspector as having highly critical work environments (Nielsen 2015). Similar ergonomic challenges of the hospital sector are recognized internationally (Hignett et al. 2013).

As a part of the renewal process of the public hospitals in Denmark, the regional councils have agreed on a common vision of involving employees in the process. This vision has given rise to several regional innovation centers (Danske Regioner 2010), facilitating activities that can be characterized as PS, like the hallway example. The purpose of PS is to contribute to the design of new and renovated hospitals and therefore also to the work systems taking place in these hospitals. The application of PS in the regional innovation centers results in accumulation of practical experiences with PS in hospital work system design. These practical experiences were the foundation for my PhD study.

1.2 PARTICIPATORY SIMULATION FROM AN ERGONOMICS PERSPECTIVE

"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 2015)

In this study, I take on the ergonomics perspective. In the thesis, the perspective is called *ergonomics*, and the practitioners and actors conducting the discipline are called *ergonomists*. I focus on three central parts of the ergonomics perspective: *a system view*, *a design orientation* and *a participatory approach*. The *system view* includes approaching workplaces as work systems, interconnections between several elements such as the physical work space, the organization of work, employees, the information employees exchange, the work tasks, and technologies and tools applied in the work (Alter 2006; Carayon 2009; Kleiner

2006). The *design orientation* is related to design of work systems for both human well-being and system performance (Wilson 2014; Edwards & Jensen 2014). The *participatory approach* is related to the term participatory ergonomics (PE), in which employees are involved in planning and controlling their own work (Wilson et al. 2005). PE in work system design benefits from employees' knowledge of the existing work system by integrating it into the design of the new work system. The purpose of PS is to identify and correct ergonomic problems during design and in this way avoid often expensive corrections after construction and implementation of the new work system (Hendrick 2008). Integration of ergonomics in work system design has improved effectiveness, reduced accidents, reduced work related disorders, increased safety and improved quality (Carayon 2006; Hendrick 2008; Vink et al. 2006).

To benefit from employees' knowledge in participatory ergonomics (PE) work system design, methods to gain access to the knowledge are required. Participatory (PS) simulation is a method to access employee knowledge. PS offers the possibility of identifying and evaluating ergonomic challenges of future work systems with the employees. In PS, the future work system is represented by a simulation medium (Daniellou 2007), e.g., in the form of full-scale mock-ups as in the example of the hallway design. Applying the medium, the employees simulate future work in the proposed work system design. The employees contribute with their knowledge by questioning and reflecting on the design, which leads to adjustments and new simulations in an iterative process (Barcellini et al. 2014). The purpose of PS is to evaluate the ergonomic conditions of the future work system and to develop design specifications to improve these conditions. The design specifications are intended to be transferred to work system designers for implementation into design (Barcellini et al. 2014). In this way, ergonomic challenges can be corrected before construction and implementation.

Involvement of employees in simulation is an applied method in work system design in the ergonomic field. However, the existing studies have mainly focused on involvement of employees in controlled simulations (Grundgeiger et al. 2013; Rousek & Hallbeck 2011; Bødker 2000; Hertzum 2003; Steinfeld 2004; Paquet & Lin 2003; Goodman-deane et al. 2014; Fritzsche 2010). Such simulations relate to usability testing. The outcomes of the experiments are not specifications based on the employees' knowledge. Instead, the outcome is analysis of the ergonomic challenges from the perspective of the ergonomist acting as an expert.

Few studies have introduced simulation in the form of PS, in which simulation is a method to design with the employees and not solely for the employees. In these studies, the ergonomist supplements the expert role with a role as planner and facilitator. However, PS is often listed among several different PE methods (McClelland & Suri 2005; Norros 2014; Wilson 2005; Nelson et al. 2013; Béguin 2011; Béguin 2007). Only a few studies have actually investigated PS and identified the elements constituting the method, e.g., the application of a simulation medium (Daniellou 2007; Broberg & Edwards 2012; Barcellini et al. 2014). Therefore, PS is recognized as an ergonomics method, but the elements of the method have gained little research attention. Yet knowledge of the elements is essential when analyzing and planning PS events in work system design. Therefore, an extension of the knowledge base on PS in work system design is important for both research and practice. In the next three paragraphs, I identify three research areas that highlight the lack of research on the PS method.

1.2.1 First research area: Influence of simulation medium

PS studies have emphasized the importance of applying a simulation medium (Daniellou 2007; Barcellini et al. 2014). Several show that simulation media have different capabilities, e.g., full-scale mock-ups to visualize room layouts and scale models to visualize the overall layout of several rooms (Bligård et al. 2014; Persson et al. 2014; Broberg et al. 2011). These different capabilities indicate that simulation media potentially can support evaluation of varying ergonomic conditions of the future work system, which also is a point commonly indicated in the literature (Hallbeck et al. 2010; Paquet & Lin 2003; Steinfeld 2004; Sundin & Medbo 2003; Watkins et al. 2008). However, the actual influence of the simulation media on ergonomic evaluation has not been investigated. I argue that extension of the knowledge base in relation to the medium's influence on ergonomic evaluation is relevant for supporting selection of simulation media in the planning of PS.

1.2.2 Second research area: Knowledge creation as outcome

Existing PS research has mainly concentrated on the benefits and outcomes, often taking the form of new design specifications (Österman et al. 2016; Broberg et al. 2011; Barcellini et al. 2014). Only a few studies have acknowledged that the process of creating the outcome include participants sharing experiences, competencies and knowledge, often in a "tacit" form (Daniellou 2007; Garrigou et al. 1995; Norros 2014; Béguin 2003). PS has been identified as a method that has potential for converting this "tacit" knowledge into "explicit" knowledge

(Norros 2014), therefore creating ergonomic knowledge in the form of design specifications. However, how this ergonomic knowledge is created has not been investigated. I argue that extension of the knowledge base in relation to ergonomic knowledge creation in PS is important for facilitating PS with a relevant knowledge creation outcome.

1.2.3 Third research area: Knowledge transfer and integration

Ergonomic research has emphasized the importance of transferring ergonomic knowledge from ergonomists to designers in the form of guidelines and standards to be integrated into design (Broberg 2007; Campbell 1996; Conceição et al. 2012; Hignett & Lu 2009; Kim 2010; Skepper et al. 2000; Wulff et al. 1999b). Yet, only a few studies acknowledge the importance of transferring ergonomic knowledge created in PS to designers for integration into design (Barcellini et al. 2014; Broberg et al. 2011; Seim & Broberg 2010). However, these studies only acknowledge but do not investigate this knowledge transfer and integration taking place subsequent to PS events. I argue that extension of the knowledge base in relation to transfer and integration is relevant for supporting planning of PS events that will have actual impact on design.

1.3 Study focus

The extensive application of PS in hospital work system design taking place in Danish innovation centers provided a unique opportunity for extending the knowledge base of the PS method. Therefore, this PhD study examines the application of PS in hospital work system design. The study was guided by three research questions addressing the three research areas identified.

RQ1: How are simulation media in participatory simulation influencing ergonomic evaluation in design of hospital work systems?

RQ2: How is ergonomic knowledge created in participatory simulation in design of hospital work systems?

RQ3: How is ergonomic knowledge from participatory simulation transferred to hospital work system design processes and integrated into design?

The three research questions support development of a PS taxonomy, providing an overview of the elements of the PS method. The aim of the PS taxonomy was to supports 1) researchers in analyzing and categorizing PS, and 2) practitioners in planning and facilitating PS. Essential terms are listed in Table 1.

Participatory simulation	Participatory simulation is a method to involve employees in imitation, exploration, and design of their own future work system. In this thesis, participatory simulation will be referred to as “PS” or “simulation.”
Hospital work system	The work system taking place in hospital workspaces. A work system consists of work practice, participants, information, technologies and tools, space, and organization (Alter 2006; Carayon 2009; Kleiner 2006).
Hospital work system design processes	The processes of engineers and architects designing future work systems. Furthermore, managers from the project owner’s organization are involved in the design decisions. The design processes take place parallel to PS events. The PS provides inputs to the design processes.
Work system designers	Engineers and architects are designers of the physical space and technologies of the new hospital work system. Furthermore, management is a designer of organizational elements of the hospital work system.
Ergonomic evaluation	Discussions and assessments of identified ergonomic conditions of the future work system.
Ergonomic knowledge	The outcome of PS in the form of design specifications based on ergonomic evaluation.
Knowledge transfer	The process of sending or bringing created ergonomic knowledge from PS events to the work system design processes.
Knowledge integration	The process of engineers and architects applying the received knowledge in work system design.
Taxonomy	Oxford English Dictionary defines taxonomy as "a system of classifying things" (Soanes 2002) based on several categories and subcategories (e.g. Sheridan 2014; Greco et al. 2013).
Practitioners	Ergonomists or other actors conducting ergonomic related disciplines, e.g., occupational health and safety (OHS) responsibility, work environment responsibility or ergonomic consultants.

Table 1: Essential terms of the study.

1.4 The empirical foundation

The empirical foundation of the study was three cases of PS taking place in three Danish innovation centers and contributing to three hospital design projects. A short introduction of the three cases follows. A thorough case exposition is presented in Section 7.

1.4.1 Case 1: Table-top simulations

The first case was part of designing a new outpatient department. The PS applied in this case was based on table-top models constituting of LEGO figures, cardboard boxes and an A0 poster (Figure 1). Health care employees from the existing outpatient department participated in the PS to explore different department layouts and work organizations through scenario acting using the LEGO figures.

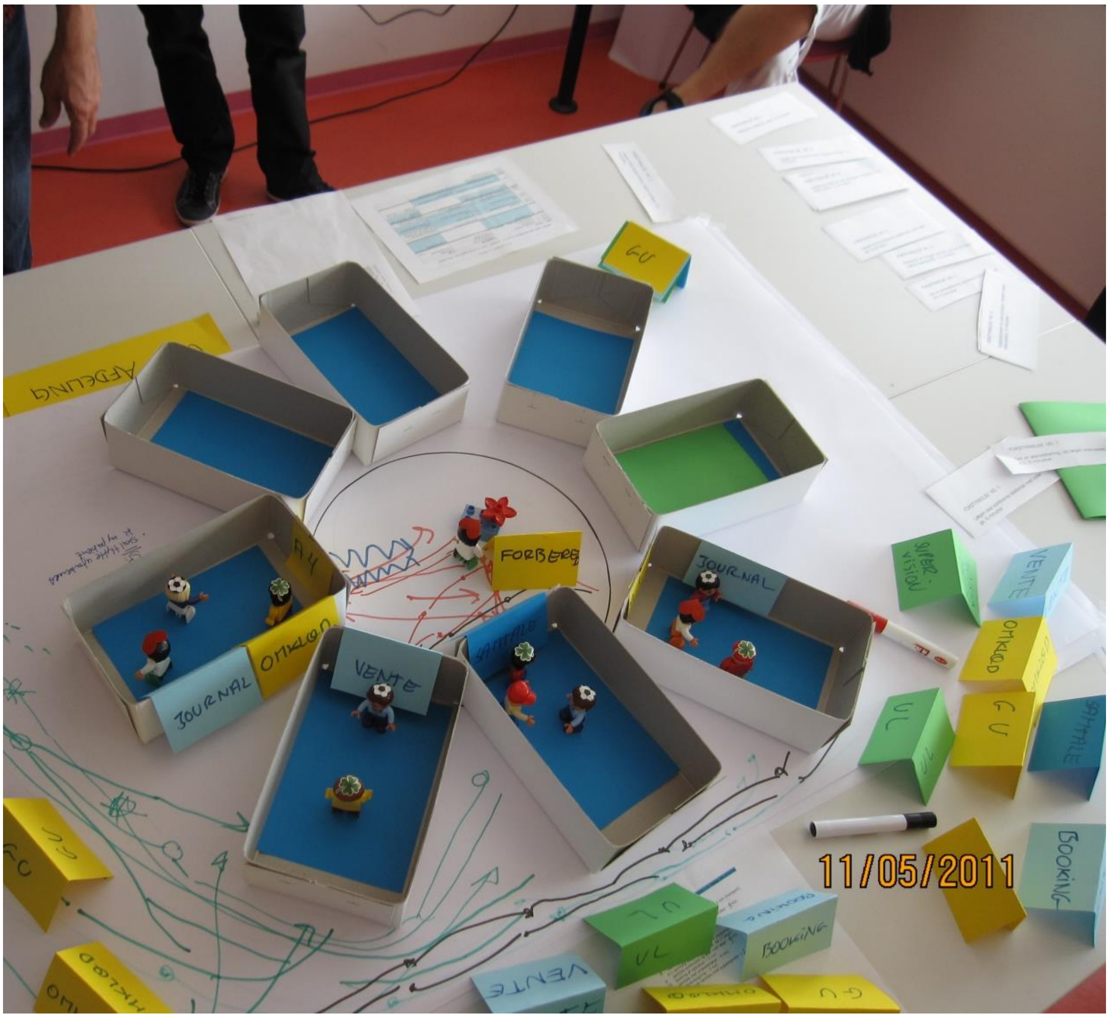

Figure 1: The table-top models applied in the first simulation case.

1.4.2 Case 2: Full-scale mock-up simulations

The hallway example described at the beginning of this introduction is from the second case, which was part of designing a new major hospital. The PS was based on full-scale mock-ups (Figure 2). The full-scale mock-ups were constructed of chipboard walls and large foam bricks, representing different possible designs of hospital rooms. In the PS, health care employees from existing regional hospitals explored and tested the future work in the mock-ups.

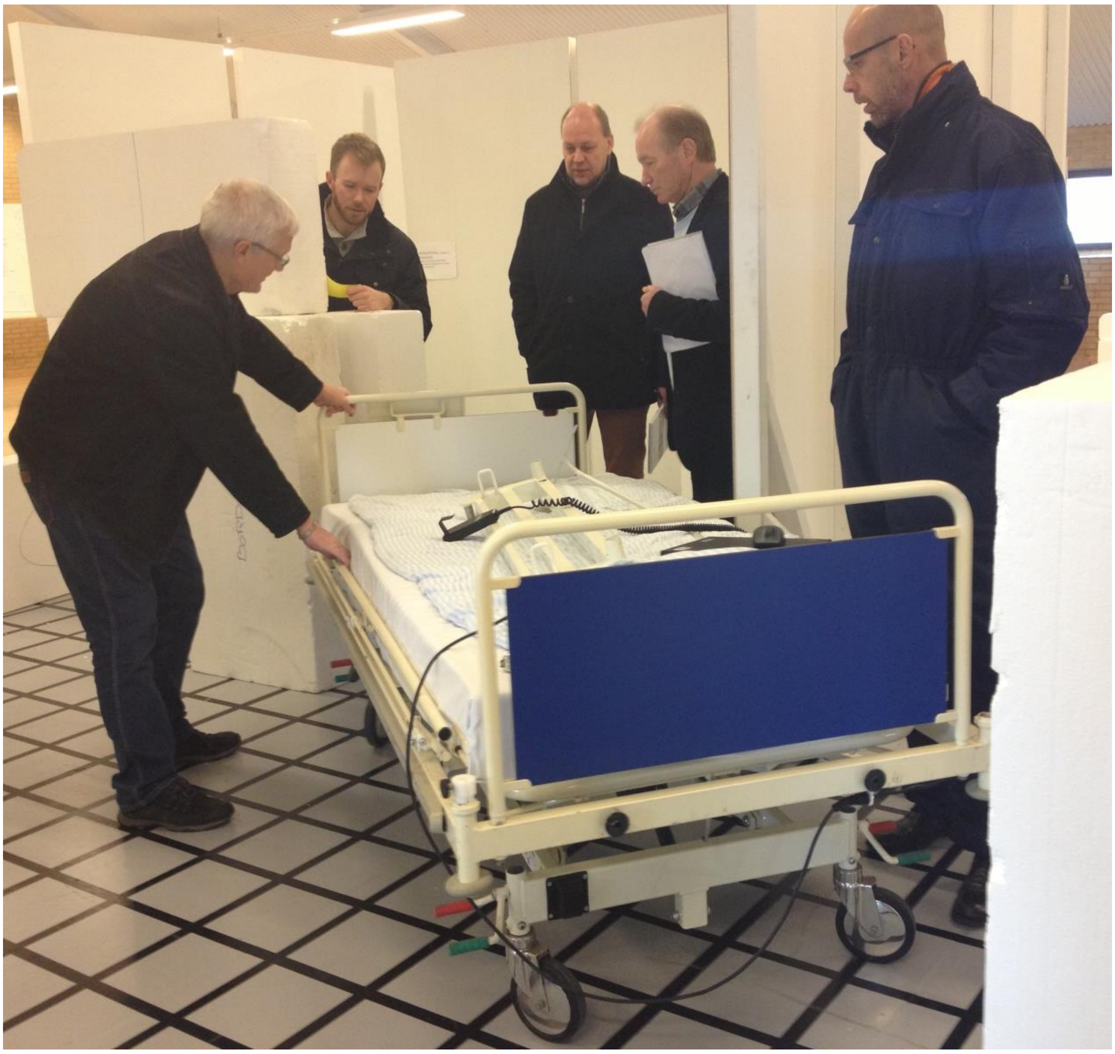

Figure 2: The full-scale mock-ups applied in the second simulation case.

1.4.3 Case 3: Blueprint simulations

The third case was part of the design and occupation of a renovated intensive care unit (ICU). The purpose was to prepare the employees before moving into the new ICU. The PS was based on blueprints of the renovated ICU, LEGO figures and LEGO bricks (Figure 3). Health care employees from the existing ICU explored the new ICU design by discussing and acting scenarios using the blueprints and LEGO figures.

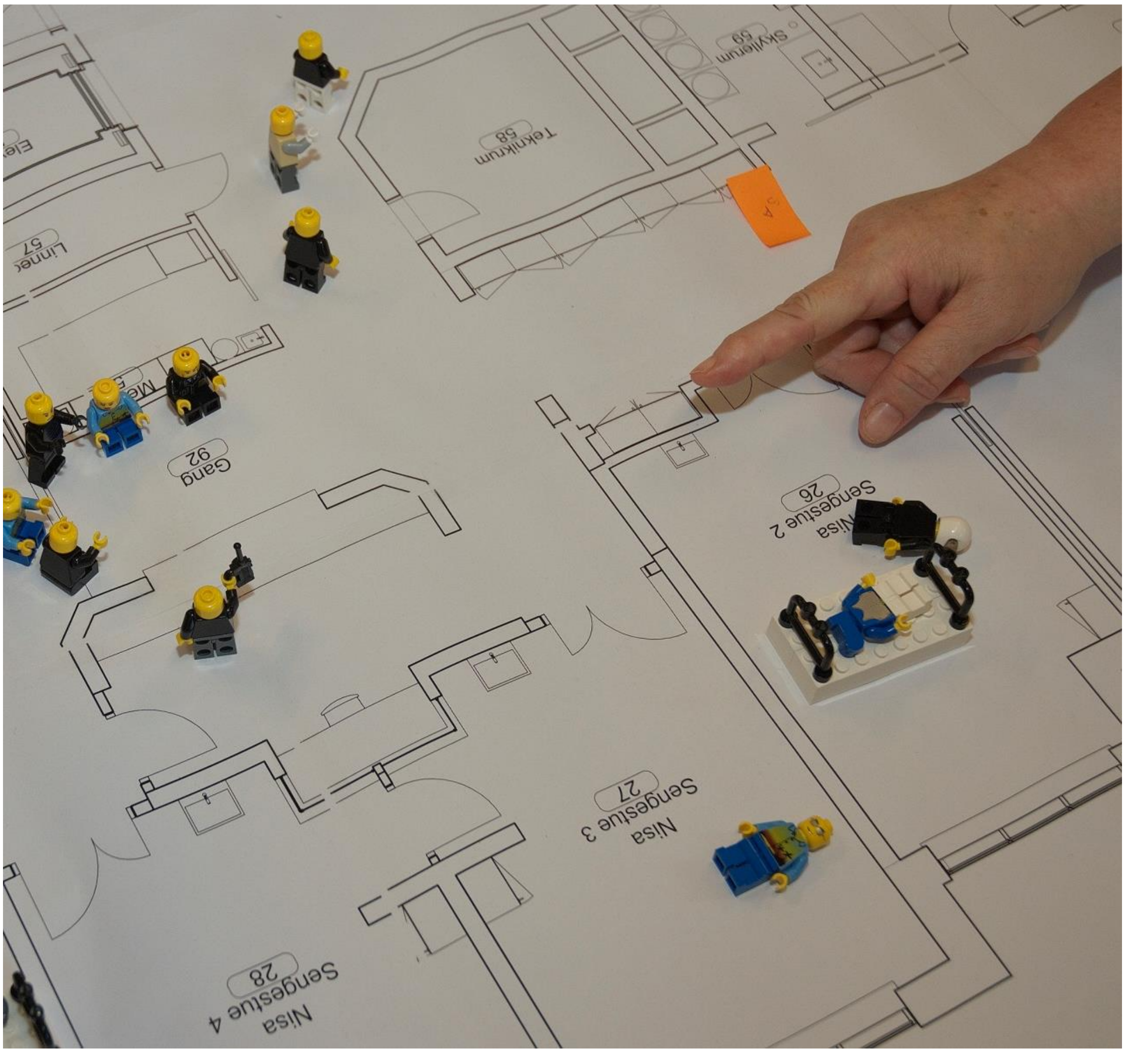

Figure 3: The blueprints and LEGO figures applied in the third simulation case.

1.5 DELIMITATIONS

This study focused on the application of PS in renewal of Danish hospitals. This delimited the study in two ways. First, the innovation centers in Denmark have mainly involved health care employees in the PS. Therefore, patients have not been the main target group. Thus, the focus of this study has mainly been on PS involving health care employees. Second, the innovation centers have mainly applied physical simulation media such as mock-ups and scale models. Computer-based media such as virtual reality have not been applied. Therefore, this study has mainly concentrated on physical simulation media in PS. However, I have investigated computer-based media through literature and visits to institutions and companies applying such media.

The third research question investigates the knowledge transfer from PS to the work system design process and integration into design. Work system design processes in the form of architectural and engineering design processes of Danish hospitals take between 5 and 10 years from the first idea to the final hospital building is constructed. Because of time limitations of the PhD study, a longitudinal study of the transfer and integration was not possible. Therefore, the study focused on the transition between PS events and design processes. Furthermore, the study has not discussed differences between architects and engineers. Instead, the focus has been on understanding the overall design process, the main design phases and how PS can contribute.

Finally, the study has concentrated on how PS is contributing with design input in the form of design specifications. Other benefits of the method such as creation of ownership, fast mastery of the new system and facilitation of mutual learning have not been addressed (Daniellou 2007; Béguin 2003; Barcellini et al. 2014), so these benefits are not included in the thesis.

1.6 STRUCTURE OF THE THESIS

This PhD study is paper-based and therefore includes three conference papers and three journal papers contributing to the three research questions. This thesis connects the papers and includes a PS taxonomy that ties together the findings. Figure 4 shows the outline of the thesis.

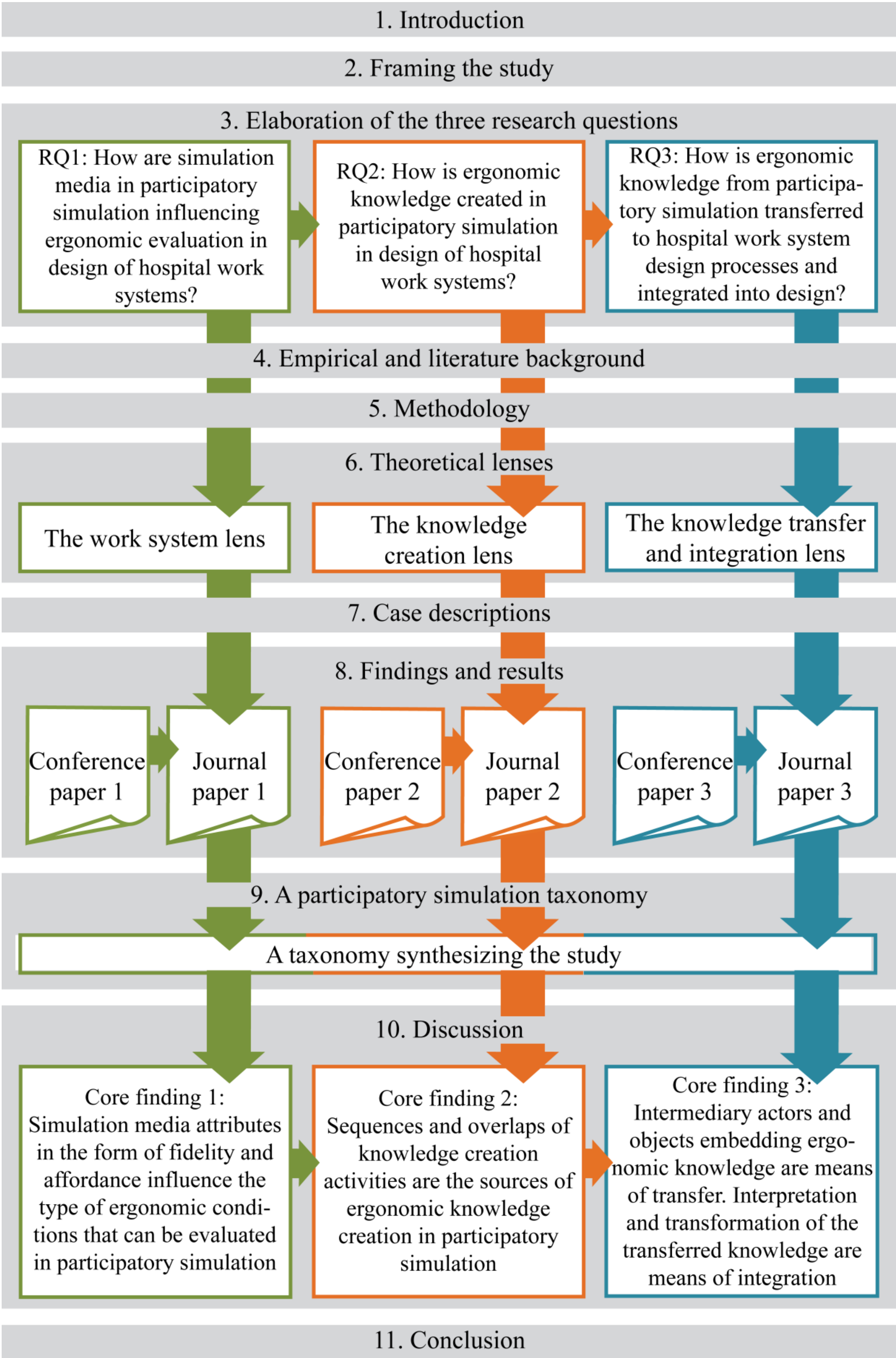

Figure 4: The outline of the thesis. The three colors and arrows indicate the three research questions, the theoretical frames, the papers, and the core findings. The sections that go across the arrows document the study across the three research questions.

2. FRAMING THE STUDY

In this section, I present how I have framed the PS phenomenon that takes place in the Danish innovation centers. I introduce three frames of understanding that I have applied throughout the study.

To approach the PS phenomenon, I adapt the framing from the work of Barcellini et al. (2014). The framing consists of three frames of understanding: *the existing work systems, the PS events* and *the work system design processes* (Figure 5). In the following paragraphs I introduce each frame and relate it to the PS phenomenon currently taking place in the Danish hospital sector.

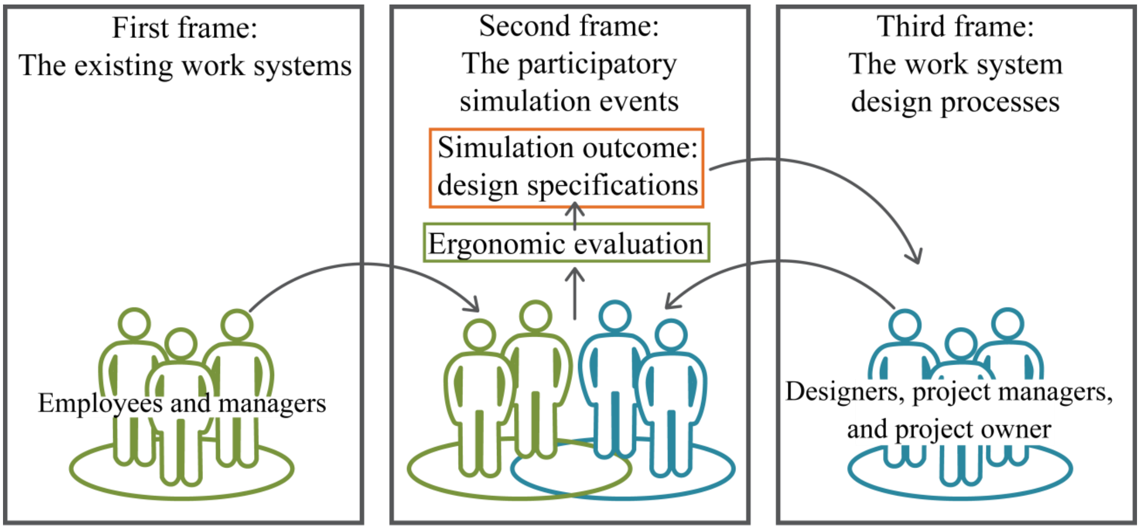

Figure 5: The three frames of PS (adapted from Barcellini et al. 2014).

The existing work systems are the current workplaces or similar workplaces populated by employees and managers. When planning PS events, *the existing work systems* are often analyzed as a "reference situation" (Barcellini et al. 2014; Nelson et al. 2013). The analysis allows identification of work activities related to both normal operations and unanticipated incidents (Daniellou 2005; Garrigou et al. 1995). The identified work activities contribute to development of scenarios, selection of simulation media and identification of possible simulation participants, to be applied and involved in the second PS frame, *the PS events* (Barcellini et al. 2014; Villeneuve et al. 2007). Applying this first PS frame to the PS phenomenon in Danish hospital renewal, *the existing work systems* are the hospitals slated for renewal, including the health care employees and managers.

The PS events are the actual simulation activities involving employees from *the existing work systems*. *The PS events* often start with presentation of the current state of work system design represented by the simulation medium (Daniellou 2007). Scenarios based on *the existing work systems* in *the PS events* support exploration of the possible forms of future work planned for the new work system (Daniellou 2005; Daniellou 2007; Garrigou et al. 1995). The purpose is to evaluate the work system design's ergonomic consequences for the future work in collaboration with the participating employees and create design specifications for the future work system (Daniellou 2007; Béguin 2007; Nelson et al. 2013). Applying this second PS frame to the PS phenomenon in the Danish hospital renewal, *the PS events* are the PS-related activities taking place in the Danish innovation centers involving health care employees and managers from the current hospitals and consulting work system designers and project managers from the *work system design processes*.

The work system design processes are overall design processes of the new work system. These processes are populated by project owners, designers and project management. The intention is that actors in *the work system design processes* take over the design specifications developed in *the PS events* (Barcellini et al. 2014). This is especially relevant if designers are not participating in *the PS events*. Applying this third PS frame to the PS phenomenon in the Danish hospital renewal, *the work system design processes* are the hospital design processes in which project owners, consulting engineers, architects and project managers develop the new work systems.

These three PS frames provided a way of framing and structuring the PhD study. However, the PS frames also simplify the PS phenomenon and approach PS as a linear process. PS is not linear and includes iterations between the frames, which I kept in mind throughout the study.

3. Elaboration on the three research questions

In the introduction, I presented the three research questions based on three identified research areas. The three research questions are elaborated upon in this section to extend the reasoning behind them.

The three research questions of the study approach the three frames of PS (Figure 6). The first and the second questions focus on *the PS events*. The third research question focuses on the transition between *the PS events* and *the work system design processes*. Each research question will be elaborated upon in the following sections.

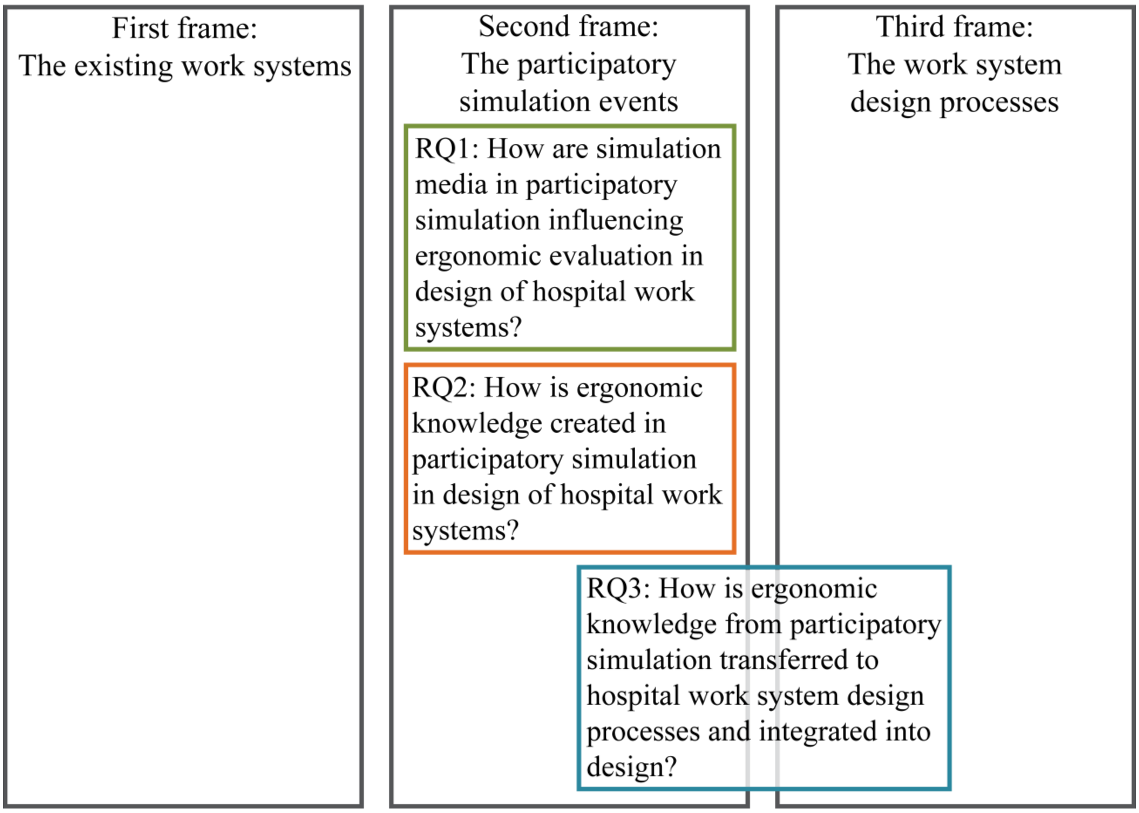

Figure 6: The three research questions in relation to the three frames of participatory simulation.

3.1 RQ1: Influence of simulation medium

PS studies have introduced several different simulation media, e.g., full-scale mock-ups, virtual reality, all for representing the future work system (Daniellou 2007; Barcellini et al. 2014). These different media have varying forms, expressions and functions and thus show different capabilities. PS studies show the variation of media capabilities, e.g., full-scale mock-ups are capable of providing an experience of the real dimensions of a room (Villeneuve et al. 2007; Bligård et al. 2014; Persson et al. 2014; Davies 2004), whereas scale models can provide an overview of overall layout (Bligård et al. 2014; Österman et al. 2016). Media capabilities identified in the literature are presented in Appendix A.

Few PS studies apply several media in one project and therefore can compare the media's capabilities (Bligård et al. 2014; Persson et al. 2014; Paquet & Lin 2003). The comparisons indicate that simulation media may be able to support evaluation of different types of ergonomic conditions, e.g., full-scale mock-ups support evaluation of special dimensions in relation to participants' own body, whereas scale models are better for evaluation of the overall room layout (Bligård et al. 2014). This support of ergonomic evaluation is indicated in the literature (e.g., Hallbeck et al. 2010; Paquet & Lin 2003; Steinfeld 2004; Sundin & Medbo 2003; Watkins et al. 2008), but how simulation media influence ergonomic evaluation in PS has not been investigated. Additionally, several studies indicate that simulation media have certain attributes, e.g., how well they represent reality (Hallbeck et al. 2010; Steinfeld 2004; Watkins et al. 2008). However, how the attributes relate to the media's influence on ergonomic evaluation has not been researched.

Extension of the knowledge base in relation to the media's influence on ergonomic evaluation is important for supporting selection of simulation media during planning of PS events. I argue that to make deliberate medium selections, we need to understand the medium's influence. Otherwise, we risk selecting a simulation medium that does not support evaluation of the intended ergonomic conditions. This argument resulted in the first research question.

RQ1: How are simulation media in participatory simulation influencing ergonomic evaluation in design of hospital work systems?

3.2 RQ2: KNOWLEDGE CREATION AS OUTCOME

Research on PS has focused on the benefits of methods such as fostering innovation (Broberg & Edwards 2012) and improving work system properties that otherwise would lead to hazards or malfunctions (Daniellou 2007). Furthermore, several studies have analyzed feedback obtained from participating employees and related this to design specifications (Barcellini et al. 2014; Broberg et al. 2011; Österman et al. 2016; Béguin 2011). Therefore, the existing research has highly focused on the outcome of PS events in the form of benefits and design specifications and not the process of creating this outcome.

Few studies indicate that the process of creating the PS outcome may include simulation participants sharing and contributing with professional experiences, competencies and knowledge relevant to the specific simulation (Daniellou 2007; Béguin 2003). Knowledge sharing is an opportunity to encounter professional worlds and confront professional knowledge (Daniellou 2007; Garrigou et al. 1995; Barcellini et al. 2014). But knowledge sharing also includes putting professional knowledge into words, which can be hard because professional experiences and knowledge can be tacit and therefore difficult to verbalize (Garrigou et al. 1995; Norros 2014). PS has been identified as a potential method for converting tacit knowledge into explicit knowledge (Norros 2014) and thus creating new knowledge in the form of design specifications for the future work system, but the process of creating this new knowledge has not been investigated.

Extension of the knowledge base in relation to PS as knowledge creation processes is important for making deliberate choices in planning and facilitation of PS. I argue that without understanding the knowledge creation taking place in PS, we risk planning and facilitating PS events that do not create the desired ergonomic knowledge. This argument resulted in the second research question.

RQ2: How is ergonomic knowledge created in participatory simulation in design of hospital work systems?

3.3 RQ3: KNOWLEDGE TRANSFER AND INTEGRATION

PS is timewise delimited events taking a couple of hours and aimed at contributing to a lengthy work system design process that often takes several years. Therefore, I see PS events as discrete events contributing to a parallel work system design process. The transition between discrete PS events and the parallel design process requires that the ergonomic knowledge created in the PS is transferred to the design process for the designers to integrate it into the design. Studies on ergonomic knowledge transfer and integration have mainly focused on transfer of knowledge from ergonomists to designers through ergonomic guidelines and standards (Broberg 2007; Campbell 1996; Conceição et al. 2012; Hignett & Lu 2009; Kim 2010; Skepper et al. 2000; Wulff et al. 1999b). Other studies have focused on how ergonomists can take a political role in the design organization to foster transfer and integration of ergonomic knowledge (Broberg & Hermund 2004; Broberg 2007; Jensen 2002; Theberge & Neumann 2010).

Therefore, research has mainly focused on transfer and integration of ergonomic knowledge created by ergonomists as ergonomics experts.

Research on PS mainly concentrates on benefits and outcomes (e.g., Seim & Broberg 2010; Hallbeck et al. 2010; Steinfeld 2004; Sundin et al. 2004). Only a few studies acknowledge the transfer and integration of the knowledge created in the PS events (Broberg et al. 2011; Seim & Broberg 2010; Barcellini et al. 2014). This knowledge is created by the employees participating in the simulation and not solely by the ergonomist as expert. The existing studies indicate that translation (Barcellini et al. 2014), materialization (Broberg et al. 2011) and the application of "transmitters" (Seim & Broberg 2010) may be important in transfer and integration. However, studies have not investigated the actual process of transferring and integrating ergonomic knowledge created in PS.

Extension of the knowledge base in relation to the transfer of knowledge created in PS to the design processes and integration in design is important for supporting the planning of PS. I argue that if the transfer and integration are not planned for, we risk PS events having low impact on design. This argument resulted in the third research question.

RQ3: How is ergonomic knowledge from participatory simulation transferred to hospital work system design processes and integrated into design?

4. EMPIRICAL AND LITERATURE BACKGROUND

Both the empirical and literature background are presented in this section in accordance with the three PS frames.

4.1 THE EXISTING WORK SYSTEMS

This section concentrates on the first PS frame (Figure 7). In this PhD study, *the existing work systems* are those in the current hospitals in the Danish hospital sector. Therefore, in this section I introduce the Danish hospital sector and the renewal initiative of the current hospitals and work systems as empirical background. Then, I describe the characteristics of the hospital sector from an ergonomic perspective and introduce the system perspective of the ergonomic field as literature background. I end this section by describing how I have applied a system perspective in this PhD study.

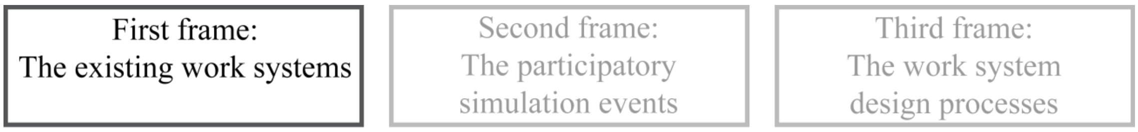

Figure 7: The first PS frame.

4.1.1 THE DANISH HOSPITAL SECTOR AND THE RENEWAL INITIATIVES

The Danish hospital sector is primarily public and includes both outpatient clinics and hospitalization. The hospitals are not centrally managed, which means that regional councils in the five regions of Denmark are responsible for the hospitals in their region (Olejaz et al. 2012). The state has overall responsibility of regulations and distribution of finances to the five regions (Olejaz et al. 2012).

In 2007, the Danish Health and Medicines Authority proposed a new initiative to the Danish hospital sector (Sundhedsstyrelsen 2007). The authority proposed that to secure a high variety of professional competencies in each emergency department, the number of hospitals should be decreased. In this way, the number of functions per emergency department per hospital would be increased, and the quality of care in emergency situations was expected to improve (Sundhedsstyrelsen 2007). Furthermore, the new approach also included the proposal of what has been termed "super" hospitals, in which more special functions are centralized. The purpose of the initiative was to improve patient care coherency, patient safety, efficiency and quality of care (Danske Regioner 2014b). The proposal of the Danish Health and Medicines Authority started the most comprehensive restructuring of the Danish hospital system in modern times (Sundhedsstyrelsen 2015).

The restructuring included renewal of Danish hospitals. To finance the renewal, the government established a foundation called the Quality Foundation (Kvalitetsfonden) in 2008 (Danske Regioner 2014c). The regional councils could apply for funding to establish the new hospitals to meet the Danish Health and Medicines Authority's requirements for emergency departments and super hospitals. The Quality Foundation assigned in total 25.5 billion DKK (3.43 billion Euro) for funding 60% of 16 building projects (Danske Regioner 2014a). The regional councils financed the remaining share, for a total investment in hospital building projects of 41.4 billion DKK (5.57 billion Euro) (Danske Regioner 2014c). Furthermore, The regional councils have started several other building and renovation projects also related to psychiatry. At the moment, 43 building projects are being initiated, ranging from small renovation projects to completely new super hospitals (Danske Regioner 2014d). The renewal process is expected to be finished around 2020, making the renewal process massive and intense in a relatively short period of time.

4.1.2 Characteristics of the hospital sector seen from an ergonomic perspective

Several ergonomic studies have been initiated in the hospital sector (e.g., Hignett 2003; Carayon & Friesdorf 2006; Hignett et al. 2013; Carayon 2012) that show that the sector has certain characteristics that distinguish it from other sectors and challenge ergonomic initiatives.

The hospital sector is characterized as being complex

The complexity is in relation to the organization and people intensity (Hignett 2003; Carayon & Friesdorf 2006; Hignett et al. 2013; Carayon 2012). The organization is influenced by the multi-professionality of the hospital sector (Hignett 2003). The many different professions result in several lines of management in the organization, in contrast to management in other sectors that often only have one hierarchical structure (Hignett 2003). The complexity of the organization influences ergonomic change projects, because the time used for implementation is significantly higher compared to other sectors (Hignett 2003).

People intensity is likewise related to multi-professionality and the variety of patients (Hignett 2003). People intensity is due to the hospital sector being people-driven, in contrast to other sectors that are technology driven, e.g., production industries (Hignett 2003). The different people in the hospital sector have different backgrounds, goals, beliefs, values and behaviors (Carayon & Friesdorf 2006). The diversity of people has consequences for ergonomic projects, e.g., defining the target group is difficult. Here the employee group is in itself heterogeneous, and the group of patients is difficult to define because every member of the population is potentially a patient (Hignett 2003).

THE HOSPITAL SECTOR IS CHARACTERIZED AS BEING "HARD WORK"

The work in the hospital sector has been described as heavy and dirty physical work and challenging emotional work (Hignett 2003). The work is also influenced by a high level of disturbances and unanticipated events (Carayon & Friesdorf 2006). Furthermore, the serious consequences of hazards and medical errors add to the pressure on the health care employees (Carayon & Friesdorf 2006). These characteristics of the health care work result in ergonomic challenges such as musculoskeletal disorders, infections, information overload and psychosocial stress (Carayon 2012; Hignett et al. 2013).

4.1.3 APPROACHING THE HOSPITAL SECTOR FROM A SYSTEM PERSPECTIVE

The characteristics of the hospital sector have resulted in ergonomic researchers proposing a system perspective (Hignett et al. 2013; Carayon & Friesdorf 2006; Carayon 2012). The argument is that the perspective can help approach the complexity. Applying a systems perspective to hospitals highlights how changes of some system elements, e.g., the physical work space, may create ripple effects and impact elsewhere in the work system, e.g., organization and communication (Hignett et al. 2013). Understanding this interconnectedness is important because experiences have showed that ergonomic interventions in the hospital sector that do not consider system interrelations are unlikely to have a significant sustainable impact (Carayon 2012). This is why Carayon (2012) argued that the work system view can help designing hospitals that do not only take into account physical needs but also social needs for communication, teamwork and interactions.

THE BACKGROUND OF THE PERSPECTIVE

The system perspective emerged as a new branch in the ergonomics discipline in the late 1970s as a reaction to the more microergonomics-oriented focus on human-machine interfaces (Hendrick 2016). A system is a set of inter-related or coupled entities with a joint purpose that exists within a boundary (Wilson 2014; Edwards & Jensen 2014; Dul et al. 2012). It is based on inputs in the form of materials or knowledge. The inputs are transformed by the coupled entities, creating outputs in the form of materials or services (Wilson 2014; Edwards & Jensen 2014).

The system perspective has been called systems ergonomics (Wilson 2014), macroergonomics (Hendrick 2016) and work systems (Carayon et al. 2012; Kleiner 2006). Systems ergonomics is "understanding the interactions between people and all other elements within a system, and design in light of this understanding…." (Wilson 2014). Macroergonomics is the analysis and design of work systems (Kleiner 2006), which are socio-technical systems, meaning that technology and people are interconnected (Klein 2014; Carayon 2006). Several scholars have developed models describing work systems and interconnectedness (Horgen et al. 1999; Carayon 2009; Alter 2006; Davis et al. 2014; Renouard & Charrier 2012; Kleiner 2006). Appendix B presents an overview of these models.

4.1.4 Application of the ergonomic systems perspective in this PhD study

To handle the complexity of the hospital sector, I drew on ergonomic scholars' argument for applying a system perspective (Hignett et al. 2013; Carayon & Friesdorf 2006; Carayon 2012). I applied a work system perspective (Klein 2014; Carayon 2006). In this way, I approached the current Danish hospitals as hospital work systems consisting of several subsystems of interrelated spatial, technical and social entities. Because I take this perspective, I see how the spatial entities of a hospital influence the rest of the work system. Therefore, I see the renewal initiatives of the Danish hospitals as not only renewal and design of hospital buildings, but also renewal and design of hospital work systems. Therefore, not only the physical space is redesigned, but this also affects and implies redesign of other parts of the hospital work system. In this way, the characteristics of the hospital sector can be affected by the renewal process by restructuring work practices and organization.

4.2 The participatory simulation events

In this section, I focus on the second PS frame (Figure 8). In this study, *the PS events* are participatory activities taking place in Danish regional innovation centers. Therefore, in this section, I describe the regional innovation centers as empirical background. Then, I describe employee participation from an ergonomic perspective and introduce the PS method as a participatory method in ergonomics as literature background. I end the section by describing how I have applied the participatory ergonomics perspective in this PhD study.

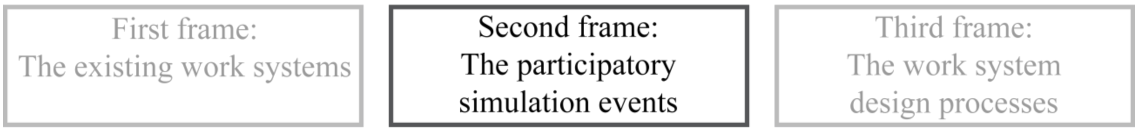

Figure 8: The second PS frame.

4.2.1 The employee participation in the regional innovation centers

As a part of the renewal of Danish hospitals, the Danish regional councils are obliged to follow a protocol on employee involvement and participation in readjustments at workplaces (Regionernes Lønnings- og Takstnævn 2008). The protocol determines that during larger readjustments such as renovating or building new hospitals, the employees must be involved and have a certain participatory democracy. To ensure employee participation, the Danish regional councils have funded seven regional health care innovation centers. The purpose of the centers is to involve health care employees in the design of new hospitals or renovation of existing hospitals. In this way, health care employees are involved in the design of their own future work systems. The intention is that employees' knowledge of existing work systems can contribute to the design of new hospital work systems. Often the involved employees are a part of a user-consortium consisting of employee representatives and work environment representatives.

The regional innovation centers take different forms. Some are physical centers, and others are temporary and movable to different locations. Some are managed by regional employees, some by existing hospitals and others by hospital designers. However, all have the employee participation purpose, and all involve some kind of visualization in the form of full-scale mock-ups or scale models.

4.2.2 Employee participation from an ergonomics perspective

A central part of the ergonomics discipline is participation of employees in analysis and design of their own future work systems (Garrigou et al. 1995; Wilson 2014; Carayon et al. 2012). Employee participation is called participatory ergonomics (PE). Noro and Imada (1991) define PE as an approach in which end-users of the ergonomics take an active role in identification and analysis of ergonomic risk factors as well as the design and implementation of ergonomic solutions. Wilson et al. (2005) defined PE as "the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes to achieve desirable goals." Participatory ergonomics often take two forms: workplace interventions and participatory design.

Participatory ergonomics as workplace interventions

Workplace interventions often aim to reduce muscular skeletal problems and improve psychosocial conditions (Laing et al. 2007; Lee et al. 2014; Hignett et al. 2005; Gyi et al. 2013; Rivilis et al. 2008; Bohr et al. 1997; Evanoff et al. 1999; Carrivick et al. 2005; Glina et al. 2011; Vogel et al. 2013). Such interventions are based on the ergonomist providing ergonomic knowledge to employees through focus groups or training.

Participatory ergonomics as participatory design

In participatory design, employees take an active part in designing their own future work systems. They are involved in analysis of existing work systems, development of work system design initiatives and implementation of design changes (Vink et al. 2006; Seim & Broberg 2010; Munoz et al. 2012; Sundin et al. 2004; Xie et al. 2015; Broberg et al. 2011; Barcellini et al. 2015; Villeneuve et al. 2007; Hallbeck et al. 2010; Daniellou 2007; McClelland & Suri 2005; Eklund 2000). This involves meetings between employees, work system designers and other stakeholders (Broberg & Hermund 2004; Béguin 2007). Several methods have been developed for this form of PE. A significant part of these methods emphasizes the need for representing and imitating the existing or future work system design (Sundin & Medbo 2003; Broberg et al. 2011; Villeneuve et al. 2007; Hallbeck et al. 2010; McClelland & Suri 2005). The application of imitations is often related to PS. Therefore, PS is a PE method.

4.2.3 Simulation as an ergonomics method

Simulation is "an imitation of the operation of a real-world process or system over time" (Banks et al. 2010) and "an attempt to duplicate the operation of a system or the behavior of a quantity of interest without incurring the expense and expending the effort to build or operate the system" (Gupta 2013). The purpose of simulation is to investigate "what if" questions through experiments (Gupta 2013; Banks et al. 2010). Simulation is therefore a method to imitate, duplicate and experiment with a system already existing in the real world or intended to be designed and implemented. Daniellou (2007) has categorized simulation in ergonomics into three types: expert-led simulation, controlled simulation and participatory simulation.

Expert-led simulation

This simulation is initiated by ergonomists and does not include employees of the future work system (Daniellou 2007). Expert-led simulation is therefore initiated by ergonomists taking an expert role. Two examples are digital human modelling and discrete event simulation. Digital human modelling is based on software in which work postures at work stations can be simulated by digital mannequins (Lämkull et al. 2009; Chaffin 2005; Fritzsche 2010; Spada et al. 2012; Thorvald et al. 2012; Chaffin 2007; Schaub et al. 1997). Discrete event simulation applies mathematical models of materials and people flow and can simulate workload (Perez et al. 2014; Laughery 2005; Banks et al. 2010).

CONTROLLED SIMULATION

This type of simulation involves employees, but as test subjects. Employees are placed within a simulated work situation and asked to complete predefined tasks. Often controlled simulation implies usability testing of mock-ups or prototypes (Grundgeiger et al. 2013; Bødker 2000; Hertzum 2003; Steinfeld 2004; Paquet & Lin 2003; Goodman-deane et al. 2014; Fritzsche 2010; Rousek & Hallbeck 2011; Hu et al. 2011; Hallbeck et al. 2010). The employee's actions are recorded and interpreted by a ergonomist (Daniellou 2007). Controlled simulation therefore treats employees as subjects of usability study for ergonomists taking an expert role.

PARTICIPATORY SIMULATION

PS is based on employees participating in simulation and design of their own future work system (Daniellou 2007). The objective of PS is to design with the employees and not solely for the employees as in expert-led simulation and controlled simulation. Employees are in PS encouraged to question and explore possible work systems designs (Daniellou 2007), including how the work system design opens or closes different types of work activity (Daniellou 2005; Daniellou 2007). Furthermore, PS includes reflections on the simulated work, leading to adjustments of the work system design, which then lead to new simulations (Daniellou 2007; Villeneuve et al. 2007; Béguin 2003). Therefore, PS events are often iterative processes based on exploring and adjusting the design (Barcellini et al. 2014). In PS, the ergonomist is not solely an expert but also a facilitator of questioning, exploration and reflection. The purpose of PS is often to evaluate ergonomic conditions of a proposed work system design and develop design specifications for improving ergonomic conditions. The design specifications are intended to be communicated to work system designers for integration in the design.

PS is consists of four interrelated components: *the participants*, *the scenarios*, *the type of simulation* and *the simulation medium* (adapted from Daniellou, 2007). *The participants* are often chosen with the intention of involving employees and other actors with relevant professional knowledge of the existing or future work system (Daniellou 2007). *The scenarios* are based on existing work systems and are stories that are simulated during PS (Marc et al. 2007). A scenario is a story about people and their activities (Rosson & Carroll 2002). Scenarios are actions of what actors do, what happens to them and changes in the setting (Rosson & Carroll 2002). There are two main *types of simulation*: experimental simulation and narrative simulation (Daniellou 2007; Barcellini et al. 2014). Experimental simulation occurs when participants personally explore the proposed design by acting out scenarios (Barcellini et al. 2014). Narrative simulation occurs when participants verbally describe future work scenarios in the proposed design (Barcellini et al. 2014; Daniellou 2007). *The simulation medium* (Daniellou 2007) is also called the simulator (Marc et al. 2007), the simulation prop (Villeneuve et al. 2007) or the intermediary object (Barcellini et al. 2014). The medium can represent parts of the future work system, which is the focus at a specific time of the design process (Béguin 2011). The medium can take several forms, e.g., mock-ups or virtual reality.

4.2.4 Application of the participatory ergonomics perspective in this PhD study

To research the employee involvement activities taking place in the regional innovation centers, I applied a participatory ergonomics perspective that enabled me to see employee participation as PS events. *The participants* are the health care employees and work system designers. *The scenarios* are future health care work. *The type of simulation* is both narrative and experimental. *The medium* is physical mock-ups and other physical models. However, the activities in the innovation centers do not only have an ergonomic purpose. Often they have several purposes, ergonomics being one among many, and some innovation centers do not explicitly identify ergonomics as one of the purposes. However, the stated purposes are often related to ergonomics, e.g., improvement of work practices related to both systems performance and human well-being. Furthermore, ergonomists are not necessarily planning and facilitating the PS events in the centers. The planners and facilitators often have a clinical or innovation consultant background. Despite this, I see the planners and facilitators as taking an ergonomist role because they initiate PS events with ergonomics purposes.

4.3 THE WORK SYSTEM DESIGN PROCESSES

This section focus on the third PS frame (Figure 9). In this study, *the work system design processes* are the processes of designing new hospitals. Therefore, in this section I describe Danish hospital design processes as empirical background. Then I describe two approaches to design processes followed by an ergonomic perspective on design processes as literature background. I end by describing how I have applied the ergonomic perspective on design processes in this PhD study.

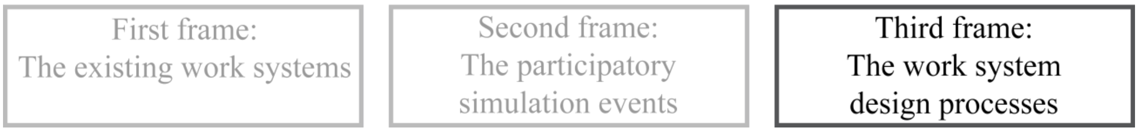

Figure 9: The third PS frame.

4.3.1 DANISH HOSPITAL DESIGN PROCESSES

The renewal of Danish hospitals is initiated and designed by engineering and architectural consortiums that work on a predefined process model developed by Danish engineering and architectural associations (FRI et al. 2013). The model varies slightly from project to project, but consists mainly of six phases (Figure 10). Each phase has a specific focus and deliverables, so the phases involve different actors that collaborate to design, plan and initiate the building project. Table 2 lists the central actors. Danish hospital design processes take between 5 to 10 years from the first idea to the final building is renovated or new constructed. PS activities in the regional innovation centers contribute in the different design phases with input to the design.

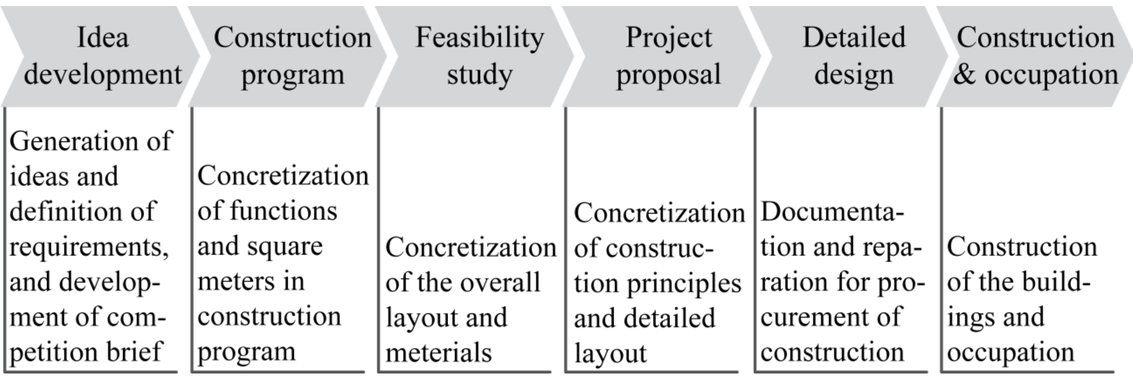

Figure 10: The six phases of Danish hospital renewal processes
(translated from FRI et al., 2013).

Actors	Description
Project owner	The project owner is the actors ordering the project. However, the project owner is neither one single person nor the direct users of the new or renovated hospital. In the Danish hospital design processes, the project owner is formally the individual regional council. However, the task is usually relocated to the individual hospital management and project steering committees (DNV-Gødstrup 2012).
Competition brief consultants	Often the project owner hires a group of consultants to assist in idea development and creation of a competition brief. The consultants are often an architectural company. The competition brief states the projects owner's needs, and the brief forms the foundation for an architectural competition (Bygningsstyrelsen 2013).
Consulting consortiums	Several consortiums participate in the competition. A consortium is collaboration between engineering and architectural companies. Based on the competition, the project owner chooses one consortium to be responsible for further hospital design in the construction program, feasibility study, project proposal and detailed design phases (Danske Regioner 2015).
Public authorities	The public authorities' main role is approving the initial ideas and the project proposal. They approve the geographic positioning of the building or the renovation.
Construction companies	In the detailed project phase, the consulting consortiums have documented the design in detail. This is the foundation for procurement for construction. Several construction entrepreneurs can contribute with their offers. One or a combination of construction entrepreneurs is selected by the project owner to start the construction of the new or renovated hospital (Danske Regioner 2015).

Table 2: The central actors of the Danish hospital design processes

4.3.2 Two approaches to design processes

Architectural and engineering design processes have been the topic of several studies that have taken different approaches. Two main approaches can be identified: a rational problem-solving approach and a social process approach (Stumpf et al. 2002). These approaches have different characteristics and can supplement each other in understanding design processes.

The rational problem-solving approach

This approach views design processes as rational ways of solving ill-defined problems (Stumpf et al. 2002). Such problems are solved through division into subproblems that are well-defined and delimited (Stumpf et al. 2002; Lawson

1997). These subproblems are interdependent and therefore result in interconnected decision areas (Cross 2005; Bendixen & Koch 2007). A way of handling interconnectivity is through predefined design phases (Cross 2005; Lawson 1997; Blyth & Worthington 2010; Stumpf et al. 2002). The main activity of the design phases is producing drawings as the result of the design process (Lawson 1997; Cross 2005).

THE SOCIAL PROCESS APPROACH

In the social approach, design is seen as "wicked" problems that cannot be divided into delimited subproblems, but instead demand several different expertise to solve (Stumpf et al. 2002). Therefore, building design is often conducted in interdisciplinary consortiums in which design actors have different responsibilities, perspectives and interests toward the design (Lawson 1997; Bucciarelli 1994; Blyth & Worthington 2010; Bendixen & Koch 2007). Within the social process approach, several researchers have argued that predefined design phases do not reveal how designers actually design (Stumpf et al. 2002; Lawson 1997; Lloyd 2000). Instead, the design process is described as social, including negotiations, politics, conflicts and alignment between the actors (Stumpf et al. 2002; Lloyd 2000; Bucciarelli 1994; Bendixen & Koch 2007; Georg & Tryggestad 2009). In the social process, drawings are a valuable tool to handle multiple interests and are therefore not the only design result (Ewenstein & Whyte 2007; Bendixen & Koch 2007). Drawings represent the state of design, e.g., a blueprint represents a building layout (Ewenstein & Whyte 2007), and have therefore been studied as the center of the social design process (Henderson 1999; Bucciarelli 1994; Whyte et al. 2007; Bendixen & Koch 2007; Ewenstein & Whyte 2007).

4.3.3 DESIGN PROCESSES FROM AN ERGONOMICS PERSPECTIVE

Within the ergonomics field, design processes have been studied in relation to how ergonomics can be integrated into design. This integration has been a central struggle, even though studies have shown several financial benefits and human well-being improvements (Goggins et al. 2008; Neumann & Dul 2010; Hendrick 2008). Several studies have therefore identified and investigated the constraints that have to be overcome when integrating ergonomics into design (Whysall et al. 2006; Helander 1999; Hall-Andersen 2013; Burns & Vicente 2000; Béguin 2011). These constraints relate to the two approaches of understanding design processes. Furthermore, ergonomic scholars investigate initiatives to overcoming the constraints for integrating ergonomics in design.

Constraints related to the rational problem-solving approach

The predefined design phases mean that decisions are made in the beginning of the design process, whereas knowledge about the future design is greatest in the late design phases (Béguin 2011). This creates a time constraint (Béguin 2011) that makes reconsideration of decisions often impossible, e.g., when an overall volume of a building is approved by authorities, it is very hard to change (Béguin 2011). Early design decisions also result in contextual constraints (Burns & Vicente 2000) in which early defined design requirements dictate which type of ergonomic solutions can be integrated, e.g., a defined size of a building limits the width of rooms and corridors. Time and contextual constraints show that different ergonomic input is relevant in different phases of the design process.

Constraints related to the social process approach

The inter-disciplinary design process can create a goal-oriented constraint (Béguin 2011). Interrelations between the different disciplines sometimes result in ergonomics integration in one area having huge impact on other design actors with concerns and design goals (Béguin 2011; Burns & Vicente 2000). In this way other actors' goals can hinder ergonomics integration. Furthermore, multiple goals can create professional boundaries between the actors (Béguin 2011; Burns & Vicente 2000).

Ergonomics integration initiative

Communication of ergonomic knowledge to designers through education (Skepper et al. 2000) and ergonomic guidelines (Campbell 1996; Wulff et al. 1999b; Wulff et al. 1999a; Kim 2010) is an initiative for overcoming the ergonomics integration constraints. However, several studies reveal that organizational factors and multiple actors' perspectives are influencing the application and interpretation of ergonomic guidelines (Broberg 2007; Wulff et al. 1999b; Jensen 2002). Other objects than written guidelines, e.g., layout sketches and recommendation booklets, support integration in other ways (Hall-Andersen & Broberg 2013; Conceição et al. 2012).

In addition, several studies have investigated how the role of the ergonomist can be a way of overcoming the constraints. Three main roles are investigated: the expert role, the facilitator role and the political role. When the ergonomist acts as an expert, he or she advises, assesses and becomes one of the multiple experts in the interdisciplinary design process (Béguin 2011; Broberg & Hermund 2004; Jensen 2002). When the ergonomist acts as a facilitator, he or she facilitates processes involving different groups of actors in the design process (Jensen 2002). When the ergonomist takes a political role, he or she strategically navigates in the social design process and mobilizes different actors to bring forward an ergonomic agenda (Broberg & Hermund 2004; Theberge & Neumann 2010; Broberg 2007; Jensen 2002; Dul & Neumann 2009).

4.3.4 Application of the ergonomics perspective on design processes in this PhD study

To investigate the Danish hospital work system design processes, I applied an ergonomics perspective. In this way, I saw Danish hospital design processes as a combination of rational problem-solving and social processes. The PS contributions to the design process are approached as ergonomic integration into the design. The ergonomics perspective enabled me to focus on the integration constraints to overcome when integrating knowledge from PS events into the hospital work system design.

5. METHODOLOGY

This section introduces the case study methodology that has been applied in the PhD study. This methodology includes several steps that are described in the following sections, including data collection methods and data analysis methods. I end the section by reflecting on my methodological choices.

5.1 THE METHODOLOGY

In the study, I applied a case study methodology. Yin (2009) defines this methodology as an experimental investigation of a contemporary phenomenon in depth and within its real-life context. PS events in the innovation centers are contemporary because they have been taken place since the renewal started in 2008. PS events are empirical and take place in the real-life context of the innovation centers. Therefore, the PS events were investigated in an in-depth study of a limited number of cases. A case study includes several steps that take place in an iterative process (Figure 11). The first step, defining research problem, is related to definition of the three research questions (Section 3). The subsequent steps in Figure 11 will be described in the following sections.

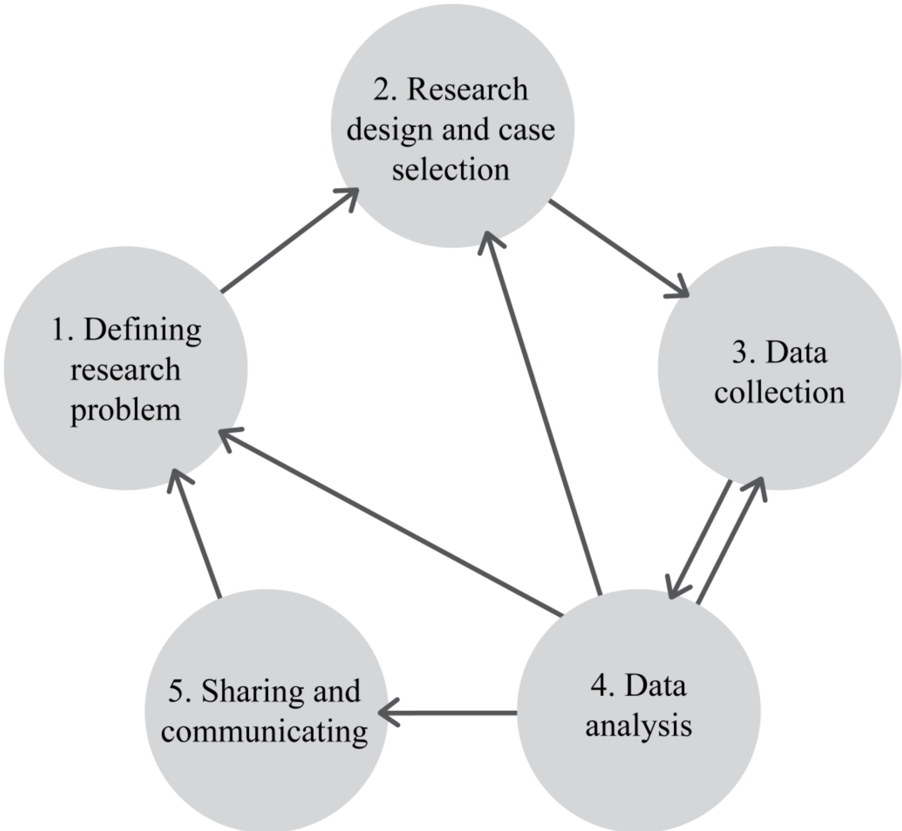

Figure 11: The iterative process of the case study methodology (adapted from Yin, 2009).

5.2 Research design and case selection

The study was based on an exploratory approach and designed as a multiple case study.

5.2.1 The exploratory approach

Exploratory studies are relevant when the knowledge base of the research topic is limited (Saunders et al. 2009). The purpose is to expand knowledge by clarifying and learning from the studied phenomenon through in-depth investigation (Saunders et al. 2009). Furthermore, studies based on limited knowledge often benefit from the exploratory approach because it allows continual adjustments of the focus as the study progresses and knowledge on the phenomenon increases (Saunders et al. 2009). After reviewing the literature, I realized that PS is a method that is rarely investigated in the ergonomics field and knowledge about the method is limited. Therefore, the exploratory approach was relevant for clarifying and learning from the PS phenomenon taking place in Danish regional innovation centers. Furthermore, because of the limited studies, a relevant direction of the study was difficult to define from the beginning. The exploratory approach allowed me to continually adjust the focus and direction as the study progressed and I got a clearer idea of the study's relevance.

5.2.2 A multiple case study design

The exploratory approach also resulted in continual identification and exploration of cases that developed into a multiple case study. The cases were identified through an introductory study to obtain an overview of the regional innovation centers and the applied PS. The introductory study showed that the innovation centers applied different types of simulation media, e.g., full-scale mock-ups, scale models. Furthermore, they applied PS at different phases of the design processes. To explore these PS variations I selected three cases based on the criterion of maximum variation (Flyvbjerg 2006), which was related to the type of simulation media and the design phase in which the PS was applied. The advantage of maximum variation is that cases can be applied in comparative studies and studies of commonalities (Eisenhardt & Graebner 2007; Thomas 2011). Cross-case commonalities are especially strong when the cases vary in maximum degree (Neergaard 2010). Table 3 shows the three cases and their variations and Table 4 show how the three cases have been applied in investigation of the three research questions.

Name of case	**Case 1: Table-top simulation**	**Full-scale mock-up simulation**	**Blueprint simulation**
Case period	Took place in 2011. This case was therefore retrospective.	PS took place in 2012 to 2015. I followed the last PS events.	PS took place in spring 2015, when I followed the PS.
Case background	Design of a new outpatient department at a major hospital in the capital region	Design of a new major hospital in the country	Occupancy process of an intensive care unit at a small hospital in the country
Type of renewal	Extension of existing hospital	Completely new hospital	Renovation of existing hospital
Simulation media	Small scale table-top models based on LEGO figures and cardboard boxes representing the future outpatient department	Full-scale mock-ups based on movable chipboard walls, large foam bricks and standard hospital interior representing different rooms of the future hospital	Small scale blueprints including LEGO figures and post-its representing the future intensive care unit
Design phase	Conceptual early design	Detailed design	Detailed design and occupation

Table 3: The three cases of the multiple-case study.

	RQ1: How are simulation media in participatory simulation influencing ergonomic evaluation in design of hospital work systems?	**RQ2:** How is ergonomic knowledge created in participatory simulation in design of hospital work systems?	**RQ3:** How is ergonomic knowledge from participatory simulation transferred to hospital work system design processes and integrated into design?
Cases applied	Case 1 and case 2	Case 1, 2 and 3.	Case 2
Analysis	Comparative study analyzing differences between simulation media and evaluated ergonomic conditions of each case.	Identification and analysis of commonalities between the knowledge creation processes in each case.	Analysis of the transfer and integration initiatives in the case.
Presented in	Journal paper 1	Journal paper 2	Journal paper 3

Table 4: The application of the cases in the investigation of the three research questions.

5.2.3 Units of analysis and case contexts

In this study, I operated with two case levels (Neergaard 2010): units of analysis and case contexts. Units of analysis were the specific PS events of each case (Tables 5, 6 and 7) which had durations between one and two hours. The specific PS events relate to the second PS frame (Figure 12). The case contexts were the design processes of the new work system and the existing hospital work systems. Therefore, the case context was the first and third PS frames (Figure 12).

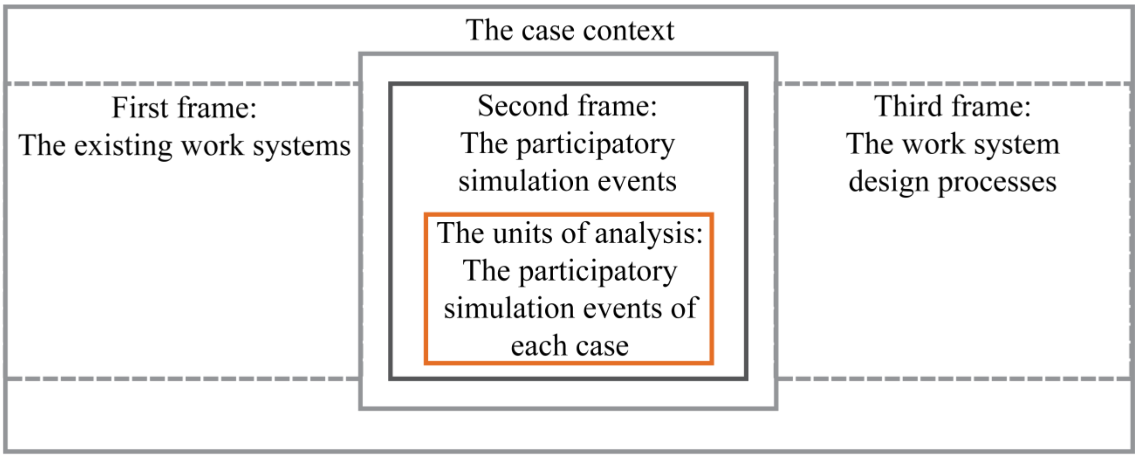

Figure 12: The units of analysis and the case contexts in relation to the three PS frames.

Case 1: Table-top simulations				
PS events	Event 1	Event 2	Event 3	Event 4
Event focus	Simulating separate examination and conversation rooms	Simulating one examination room per two conversation rooms	Simulating multifunctional examination rooms and staff area	Simulating multi-functional examination rooms and staff area
Participants	- Chief surgeon - Nurse - Medical secretary - Consultant from industry - One simulation consultant - Three researchers			- Chief surgeon - Three nurses - Two doctors - Two consultants from industry - Three researchers - One simulation consultant

Table 5: PS events as the units of analysis in case 1.

Case 2: Full-scale mock-up simulations						
PS events	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
Event focus	Simulating reception and back-office area in bed ward	Simulating examination room in out-patient department	Simulating depot in bed ward	Simulating hospital bed lift in corridor	Simulating small cancer day treatment room	Simulating large cancer day treatment room
Partici-pants	- Four secretaries - Two charge nurses - One hospital management staff member - Two IT consultants - One project employee - Two center employees		- One nurse - Two charge nurses - Two project employees - One center employee	- One orderly - One technical employee - Two project employees - Two technical consultants - One architect - One engineer - Two center employees	- Two charge nurses - One nurse - Two center employees	

Table 6: PS events as units of analysis in case 2.

Case 3: Blueprint simulations				
PS events	Event 1	Event 2	Event 3	Event 4
Event focus	Simulating the work tasks within the new intensive care unit (ICU) layout based on single bedrooms and redesigning the organization of work and work practices			
Partici-pants	- Two ICU nurses - Three coordinating ICU nurses - One physiotherapist - One charge nurse - One nurse in charge of work practice development - One facilitator from the region	- Three ICU nurses - One coordinating ICU nurse - One ICU service assistant - One ICU medical secretary - One charge nurse - One nurse in charge of work practice development - One facilitator from the region	- Four ICU nurses - Six coordinating ICU nurses - One occupational therapist - One charge nurse - One nurse in charge of work practice development - One facilitator from the region	- Three ICU nurses - Three coordinating ICU nurses - One occupational therapist - One ICU service assistant - One ICU medical secretary - One charge nurse - One nurse in charge of work practice development - One facilitator from the region

Table 7: PS events as units of analysis in case 3.

5.3 DATA COLLECTION

Data collection was based on observations, video recordings, interviews and documents. Table 8 shows an overview of the collected data of the three cases. These different types of data were collected to explore specific PS events as the units of analysis, but also the broader case contexts (Figure 13). The next sections describe and reflect upon the different data collection methods.

	Table-top simulations	**Full-scale mock-up simulations**	**Blueprint simulations**
Collected data	- Video recordings of the PS events were available from former project members - Interviews n=11 - Documents: Project reports	- Observations of the PS - Observations of work systems at existing hospitals - Video recordings of the PS events - Interviews n=22 - Documents: Competition brief, design brief, and PS summaries	- Observations of the PS events - Video recordings of the PS events - Interviews n=5 - Documents: PS summaries
Collection period	November 2013-October 2014	October 2013-January 2015	February 2015-June 2015

Table 8: Overview of the data collected in each of the three cases.

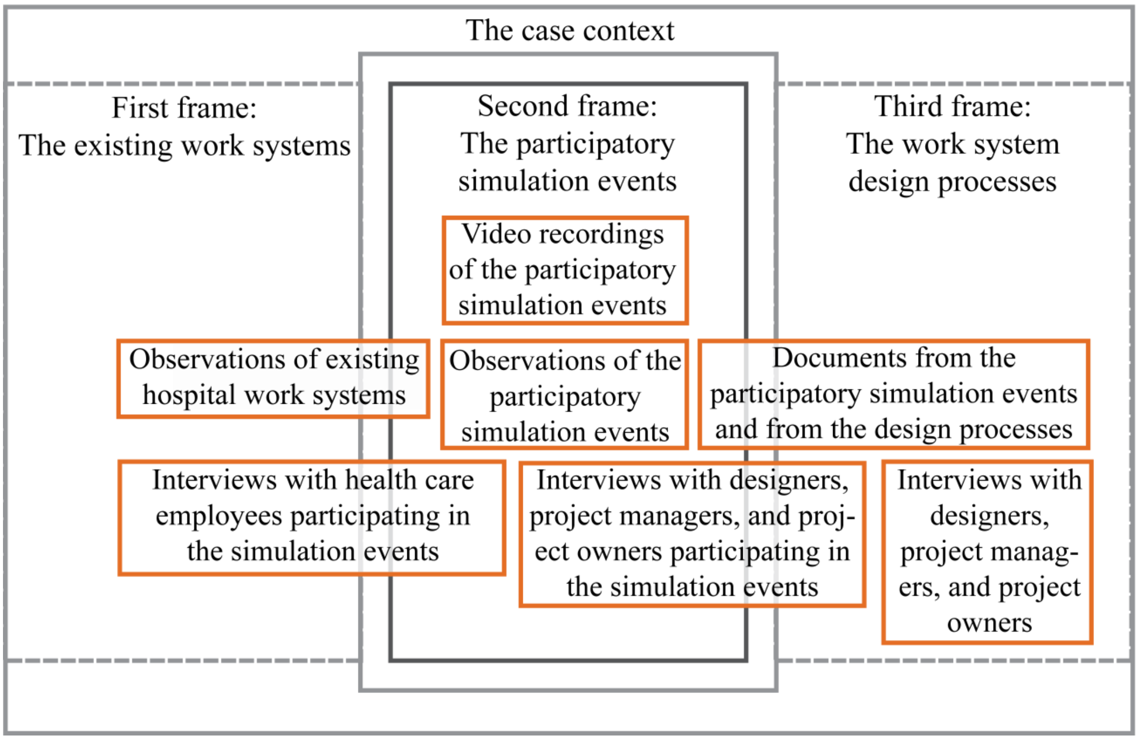

Figure 13: The collected data in relation to the three PS frames.

5.3.1 THE VIDEO RECORDINGS

Video recordings capture the audio and visual parts of naturally occurring data in real time (Heath et al. 2010). Naturally occurring data means that the activities are happening independently of the actions of the researcher (Potter 2004). Therefore, naturally occurring data differ from interviews, questionnaires and research experiments. Furthermore, video data can be revisited with different analytical focuses in an iterative process of analysis (Heath et al. 2010). Therefore, video recordings are especially relevant in exploratory studies in which the research focus and analysis continually develop (Jewitt 2012).

Because of these benefits, I chose to record the PS. I saw PS events as naturally occurring data because they were relatively independent from my actions as a researcher: They would have taken place even if I was not present. PS events also included visual elements such as participants interacting with simulation media, which the video was able to capture. Furthermore, being able to revisit the recordings several times was important for developing the exploratory approach of the PhD study.

INITIATING THE VIDEO RECORDINGS

Two important things to consider when initiating video recordings are the position of the camera and the selection of the image (Heath et al. 2010; Jewitt 2012). In the video recordings of the first case, the table-top simulations, the camera position was fixed. To be able to compare the cases, I chose a fixed camera for the recordings of the second and third case. Furthermore, the fixed camera is less intrusive and noticeable (Heath et al. 2010). The selection of the image is identification of what to record, also called "finding the action" (Heath et al. 2010). This requires to some extent familiarity with the setting to know where the activities take place. However, in the PS events, I only had a short time to scout out the place before the simulations started, which sometimes challenged me when I was positioning the camera.

CHALLENGES OF VIDEO RECORDINGS

When working with video recordings as a data collection method, three challenges have to be taken into account. The first is that analysis of video is highly time-consuming compared to other types of data because video has both an audio and a visual dimension to analyze (Heath et al. 2010). I had to consider this into my planning. The second challenge is the sensitivity of video as medium, in the sense that being recorded can be transgressive for some people. Therefore, using video recording requires building of trust among the participants (Heath et al. 2010). In my study, I did not have much time to establish this trust. Therefore, I chose from the start of the PS events to be explicit about how the recordings had a research purpose. This resulted generally in acceptance by the PS participants. The third challenge is the influence of the camera on the participants' behavior (Heath et al. 2010). The renewal of Danish hospitals is a politically sensitive topic that has been criticized and defended several times in the media. In light of this, the PS participants might have intentionally or unintentionally adjusted their behavior toward the recordings. Despite this, I still identified very politically sensitive discussions taking place in the PS events, which was interesting from a research perspective, but also increased my feeling of responsibility as a researcher to handle the recordings ethically.

5.3.2 The observations

I was not allowed to video record all activities related to the PS events, e.g., introductory meetings were not recorded. Therefore, I supplemented the video recordings with observations of the PS events and the activities taking place before and after the events. Furthermore, I conducted supplemental observations of work systems in the existing hospitals.

Initiating the observations

To focus my observations, I applied an observation guide (see Appendix C). The observation guide was developed based on an initial literature review and was continually adjusted during the study. I took both descriptive notes to record an event and reflective notes to document my reflections and interpretations (Justesen & Mik-Meyer 2012c).

Three different research roles in observations studies have been defined: complete observer, observer as participant, participant as observer and complete participant (Gill and Johnson (2002), in Saunders et al., 2009). These roles are related to how much the researcher takes part in the activity observed and whether the identity of the researcher is concealed or revealed. I took the roles as observer as participant. I was explicit about my identity as a researcher and informed the PS participants about my study. I intended to maintain a distance by not asking questions or in other ways interrupting the PS events.

To supplement the observations of the PS events in the second case, I followed two of the simulation participants in their daily work. Here I also took the role as observer as participant and shadowed the individuals throughout a working day

(Justesen & Mik-Meyer 2012c). These observations were less structured than the observations of the PS events and focused on understanding the health care employees' existing work systems.

CHALLENGES OF OBSERVATIONS

The observations of PS events and hospital departments were conducted within a limited time span. In such situations, the researcher runs the risk of misunderstanding parts (Gold (1969), in Justesen and Mik-Meyer, 2012c). In this study, the risk of misunderstanding is related to the health care sector's clinical language about procedures, diagnoses and technologies. I was aware of the risk of misunderstanding words or expressions, so before each PS event, I researched the typical clinical work of the particular work system that was the focus of the PS. Furthermore, before and after the PS events, I asked the simulation facilitators and participants to explain words and expressions.

5.3.3 THE INTERVIEWS

Kvale (1996) defines the purpose of interviews as obtaining "descriptions of the life world of the interviewee with respect to interpreting the meaning of the described phenomenon." Therefore, the interview is a way to study a phenomenon from the perspective of the interviewee. To understand PS from the view of the participants, I interviewed several participants. Additionally, to understand PS and the hospital work system design processes from the view of designers and project owner, I interviewed several actors in the broader case context. Tables 9, 10 and 11 present the interviewees.

INITIATING THE INTERVIEWS

During observation of the PS events, I identified simulation participants to interview and selected them based on maximum variation (Flyvbjerg 2006), which was related to the interviewees' professional backgrounds and organizational positions. The interviewees of the broader case context were identified based on the snowballing principle (Neergaard 2010), in which I asked interviewees to recommend new interviewees. The interviewees identified through snowballing were selected based purposive sampling (Miles & Huberman 1994). Here, I was especially interested in interviewing actors from the project owner's organization and the design organization.

The interviews were semi-structured. The interview guide (see Appendix D) consisted of an outline of topics with related questions (Kvale 1996). The semi-structured interview is relevant for exploratory studies because it leaves room for deviating from the guide when unexpected and interesting topics arise during the interview (Justesen & Mik-Meyer 2012b). In this way, I gained new insights and adjusted the interview guide accordingly

Case 1: Table-top simulations					
	From PS event 1	**From PS event 2**	**From PS event 3**	**From PS event 4**	**From the broader case context**
Interviewees n=11	- Nurse - Medical secretary - One consultant from industry - Two simulation consultants - Two researchers			- Doctor - One consultant from industry	- Two project leaders of the innovation center

Table 9: Interviewees from case 1: The table-top simulations.

Case 2: Full-scale mock-up simulations							
	From PS event 1	**From PS event 2**	**From PS event 3**	**From PS event 4**	**From PS event 5**	**From PS event 6**	**From the broader case context**
Interviewees n=22	- One secretary - One IT consultant - One hospital management staff member - Two charge nurses		- One charge nurse - Two project employees	- One orderly - One architect - One technical consultant - One engineer	- One charge nurse - One nurse		- One project manager - Two innovation center employees - Three architects - One managing architect - One construction engineer - One occupational health and safety consultant

Table 10: Interviewees from case 2: The full-scale mock-up simulations.

Case 3: Blueprint simulations					
	From PS event 1	**From PS event 2**	**From PS event 3**	**From PS event 4**	**From the broader case context**
Interviewees n=5	- One coordinating nurse	- One coordinating nurse - One ICU service assistant	-	-	- One charge nurse - One nurse in charge of work practice development - One facilitator from the region

Table 11: Interviewees from case 3: The blueprint simulations.

Interviews with the simulation participants of the first case were initiated 3 years after the PS events. Interviews with the simulation participants of the second and third cases were initiated a couple of days after the PS events. Most were conducted by the phone because of distances and the highly varying work schedules of the hospital employees. The interviews in the first case and the majority of the interviews with actors from the broader case context of the second and third cases were face-to-face interviews. The interviews in all cases had durations between one and two hours. Most interviews were audio recorded, and the parts related to the research questions were transcribed. Some interviewees declined to be recorded or recording was not possible, and in these situations, I took thorough notes.

Challenges of interviews

Compared to face-to-face interviews, telephone interviews have challenges, e.g., a significant part of a semi-structured interview is building trust so the interviewee feels comfortable revealing personal opinions (Saunders et al. 2009). This trust is especially built through personal contact (Saunders et al. 2009). Therefore, I prioritized talking face-to-face with potential interviewees at the end of the PS events to explain about myself and the purpose of the subsequent interview. Furthermore, I had to take into account that the interviews of the first case were about PS events that took place 3 years ago. That might have influenced the responses.

5.3.4 The documents

To understand the context of the three cases, I collected documents related to the cases. The advantage of documents as data sources is that they are created independently from the researcher (Justesen & Mik-Meyer 2012a). I collected and studied reports documenting the current results of the projects in the three cases and design briefs produced as a part of the building design process.

5.4 Data analysis

Analysis and interpretation of the data have been based on an abductive approach in which mixed methods analysis and qualitative analysis methods haven been applied. The analysis approaches and analysis methods are elaborated upon in the following sections. The specific analysis methods are described in details in the papers of this study (see Section 8).

5.4.1 THE ABDUCTIVE APPROACH

Alvesson and Kärreman (2011) argue that the deductive and inductive approaches are based on a clear separation of theoretical concepts and established knowledge from empirical material. The abductive approach challenges this separation by encouraging switching back and forth between the empirical world and the theoretical world. In this way, the research process is iterative because empirical material and theoretical concepts inform each other (Alvesson & Kärreman 2011; Dubois & Gadde 2002). In switching, empirical fieldwork and the application of theoretical concepts are simultaneously evolving (Dubois & Gadde 2002). Therefore, data collection and the search for complementary theories and studies take place in parallel. Figure 14 shows a comparison of the abductive approach and the deductive and inductive approaches.

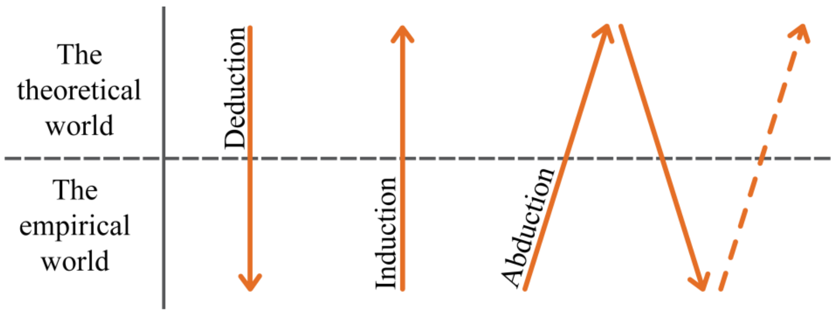

Figure 14: Illustration of deduction, induction, and abduction approaches (adapted from Alvesson & Sköldberg 1994).

I applied the abductive approach because its iterative nature supported the exploratory approach of this study, whereby the research focus continually developed. I switched back and forth between studying the empirical cases and studying the literature. In this process, empirical insights from the cases made me search for relevant literature and theoretical concepts to assist as analytical lenses. However, the empirical data often did not completely fit the literature, which made me further explore the data and so on. This resulted in several iterations of analysis, in which the analysis was continuously refined. The iterations can be seen in the three conference papers and the three journal papers (see Section 8). The conference papers were forerunners for the journal papers, therefore showing part of the analytical iterations.

5.4.2 QUALITATIVE AND MIXED METHODS ANALYSIS

The data collected (see Section 5.3) is qualitative data. When analyzing this data with the abductive approach, I both did qualitative data analysis and mixed methods data analysis. The qualitative analysis was based on identification of patterns across the data, using coding as the analysis method (Miles & Huberman 1994). The mixed methods analysis was based on principles from mixed methods research, a class of research in which the researcher mixes or combines quantitative and qualitative research techniques in a single study (Johnson & Onwuegbuzie 2004). The mix can occur at different stages of the research. Often it occurs during data collection, when both quantitative and qualitative data are collected, but it can also occur during data analysis (Johnson et al. 2007). When the latter occurs, it often includes data transformation. In this study, I converted qualitative data into numerical entities that were quantitatively analyzed (Johnson & Onwuegbuzie 2004). Figure 15 shows the qualitative and mixed methods analysis.

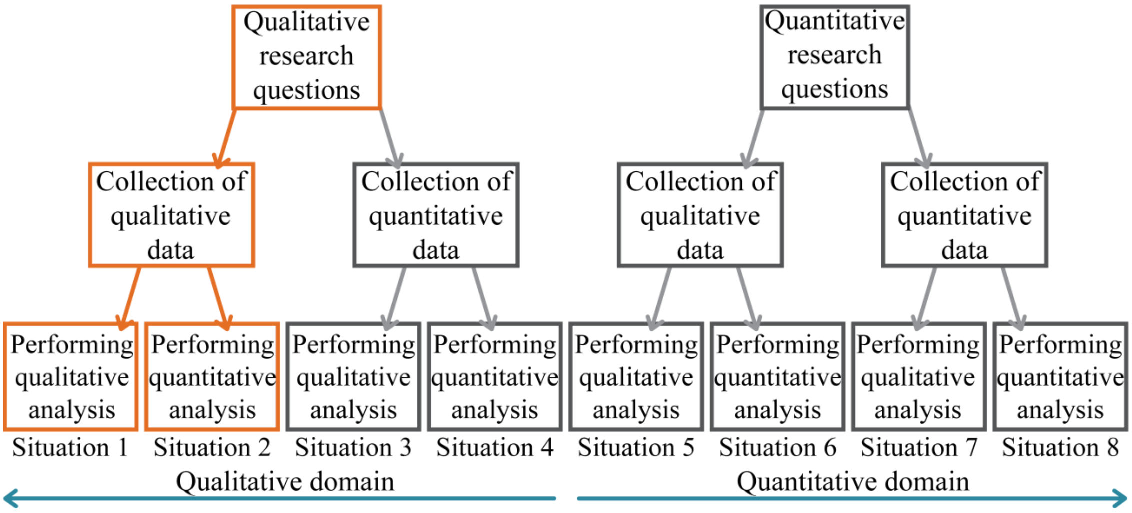

Figure 15: Data analysis continuum (adapted from Johnson & Onwuegbuzie 2004; Johnson et al. 2007). Situations 1 and 8 are mono-method analysis. All situations in-between are mixed methods analyses. The highlighted paths are applied in this study.

The mixed methods analysis was used to supplement the qualitative analysis. Furthermore, the time-intensive analysis of video recordings has been argued to benefit from systematic mixed methods analysis in which the video is coded to generate quantitative data to explore patterns across recordings (Jewitt 2012).

5.5 SHARING AND COMMUNICATING

I shared and communicated my study both in the scientific community and in the practice community. Sharing in the scientific community took the form of the three conference papers and the three journal papers presented in Section 8. Furthermore, I presented at scientific conferences to communicate subresults of the study. Sharing in the practice community took the form of presentations at professional conferences and events (see page vi and Section 5.6.1). This gave me new insights into my research from ergonomics practitioners.

5.6 METHODOLOGICAL REFLECTIONS

This PhD study investigated PS events that are naturally occurring (Potter 2004), taking place in the real and not always controllable world. Consequently, the study is not easily replicable research taking place in controlled labs. The type of research I have initiated thus has consequences for its validity, generalizability and reliability.

5.6.1 VALIDITY

Validity is related to the extent to which the results of the research accurately reflect the studied phenomenon (Collis & Hussey 2009). Case studies have been criticized for having a tendency to be subjective and based on the researcher's interpretations. However, Flyvbjerg (2006) argues that case studies contain no greater subjectivity and bias than other methods of inquiry if specific initiatives are taken. Lincoln and Guba (1986) identified three initiatives: *peer debriefing*, *triangulation* and *member check*.

I applied *peer debriefing* in the research community and the practitioner community (Guba 1981). The peer debriefing in the research community took place in the research group I was part of, at scientific conferences and during my stay abroad. In the research group, I shared research challenges and gained critical questions that enabled me to consider alternative explanations for my interpretations. In the scientific conferences, I presented subanalysis and obtained feedback from the broader research community that enabled me to turn the three conference papers into the three journal papers. During my stay at Wisconsin University in the Center for Quality & Productivity Improvement, the research group and center director, professor Pascale Carayon, challenged my data and analysis. This pushed me to refine my arguments, which contributed to transforming conference paper 3 into journal paper 3.

Peer debriefing in the practitioner community took place at professional conferences and through the advisory group. At the professional conferences, I gained feedback on my research from ergonomics practitioners. Their experiences put my research in a practical application perspective, encouraging me to communicate the results of the study as guides for practitioners (see Section 9.4). Furthermore, my advisory group offered reality checks of my research throughout the study was central to ensuring that my research was relevant for practice.

I applied *triangulation* based on data triangulation and method triangulation (Guba 1981). Data triangulation was based on the video recordings, observations, interviews and documents. Even though the video recordings often were the central data applied in analysis, the other data types enabled me to understand the reasons behind participants' actions in the recordings. Method triangulation was based on applying different analysis methods to the same data, e.g., conference paper 1, journal paper 1 and 2 all include parts of the same data that are analyzed in three different ways.

I applied *member check* based on presentation of my results to participants of the PS events. In all three cases, I had the chance to review video recordings before I interviewed the participants. This enabled me to define initial interpretations and afterward validate and further develop these during the interviews. For instance, in the third case, I obtained a deeper understanding of the discussions during the PS events through the subsequent interviews. Furthermore, in all three cases, I had close contact with the simulation facilitators, who gave feedback on my interpretations. The member check enabled me to validate interpretations and helped me focus my data collection, e.g., in the second case, the facilitators directed my attention to the transfer of knowledge from PS to designers.

5.6.2 Generalizability or transferability

Generalization means the extent to which results can be extended to a wider population (Collis & Hussey 2009). Yin (2009) stated that case studies and especially single case studies have limited generalizability to a wider population. However, Flyvbjerg (2006) argues that formal generalizability is overrated and learning from examples is a valuable outcome of case studies. He introduces the term transferability, meaning principles from one or several case studies can be transferrable to similar contexts (Flyvbjerg 2006; Lincoln & Guba 1986). Case studies cannot create conclusions that will hold in all times and in all places, but can result in knowledge that is relevant for other similar contexts. Lincoln and Guba (1986) identify two initiatives to ensure transferability: *purposive sampling* and *descriptive data*.

Purposive sampling is not intended to be representative for a wider population (Guba 1981). Instead, it is based on specific criteria that enable comparison between cases. The three cases of this study was selected on the maximum variation criterion, which is a criterion for purposive sampling (Flyvbjerg 2006). The purpose was to compare the cases but also to look for commonalities. Identification of commonalities across cases that vary in maximum degree are considered highly transferrable because the common parts take place in all the cases, despite their variations (Neergaard 2010). *Descriptive data* is "thick" data that includes a lot of information about the specific case (Lincoln & Guba 1986). Presenting this type of data will enable readers to compare the case to other possible case contexts. Therefore, transferability depends on the match of characteristics between the contexts (Lincoln & Guba 1986). Therefore, I determined to include thorough case descriptions in my papers and in this thesis.

5.6.3 Reliability

Reliability means absence of differences in results if the research was repeated (Collis & Hussey 2009). Reliabilities of case studies have been questioned because case studies are highly context dependent. This means that replication of the case study within another but related case context will not necessarily result in consistent findings (Thomas 2011). However, the reliability of case studies can be increased through *audits* (Lincoln & Guba 1986).

Audits involve letting other researchers or actors check the analysis (Lincoln & Guba 1986). I mainly based my audit initiatives on practitioners. During presentations at professional conferences, I presented data to practitioners and asked them to discuss and interpret them. For instance, I presented pictures of my three cases and asked practitioners to discuss when to apply the three simulation media. Their discussions confirmed my analysis. This was a central input for my development of the PS taxonomy in Section 9.

Furthermore, I invited five ergonomist consultants to analyze parts of the video recording as co-analysts. I had prepared 10 minutes of edited recordings of the first and second cases that I showed to the consultants. First, I asked them to describe their immediate reactions to the recordings. The responses helped me focus my analysis approach of knowledge creation in conference paper 2 and journal paper 2. Second, I asked the consultants to describe which ergonomic conditions they were able to evaluate from the video recordings. They identified several ergonomic conditions that I had identified in my analysis in conference paper 1 and journal paper 1. Third, I asked the consultants to explain which ergonomic conditions they could evaluate by applying the method in general and why they think they would be able to evaluate those conditions. Here the consultants reflected on the influence of the simulation media, which I included in the analysis in journal paper 1.

6. THEORETICAL LENSES

I used three theoretical lenses to view and analyze the cases in three perspectives. Each lens supported one of my research questions. In this section, I review the theoretical lenses, supplementing the theoretical parts of the journal papers.

6.1 THE WORK SYSTEM LENS

The work system lens originated from sociotechnical systems theory (Trist 1981). The theory united engineering design of technical solutions with management design of social organization (Trist 1981). Sociotechnical systems thinking has spread to several different fields such as engineering systems (de Weick et al. 2011), branching off ergonomics as systems ergonomics (Wilson 2014), macroergonomics (Kleiner 2006) and work systems (Carayon 2009).

Applying the work system approach (Carayon 2009; Kleiner 2006) as a theoretical lens enabled me to see the hospital design projects in Denmark as design of not only the physical building and installations, but of work systems that included technical elements such as the physical building and installations and social elements such as organization of work. In this way, I saw that the design decisions of the engineers and architects affected the social elements that would take place in the new work systems. This impact was revealed in the PS events in which hospital employees evaluated the future ergonomic conditions of the proposed hospital design. These conditions were related to the physical space and technologies but also to organizational elements. This directed me towards analysis of how simulation media influence evaluation of ergonomic consequences of both the technical and social elements of hospital work systems. The analysis investigated RQ1, and is presented in journal paper1.

6.2 THE KNOWLEDGE CREATION LENS

The knowledge creation lens originated from the knowledge management field, drawing on organizational science which sees knowledge as an organizational resource or asset (Baskerville & Dulipovici 2006). The definition of knowledge varies between the different branches of the field, but I have applied the definition of Davenport and Prusak (2000): "Knowledge is a fluid mix of framed experience, values, contextual information, and expert insights that provides a framework for evaluating and incorporating new experiences and information." A central part of knowledge is experiences because knowledge develops over time and through experiences (Davenport & Prusak 2000). The focus on experiences enabled me to see the simulation participants' individual professional experiences as knowledge, which they brought to the PS events.

Furthermore, the knowledge creation approach has a western origination and a Japanese origination (Chen & Huang 2012). The western origination focuses on how knowledge can be accumulated and reused, often in relation to information systems (Baskerville & Dulipovici 2006). The Japanese approach focuses on how knowledge is created among individuals and organizations (Nonaka & Takeuchi 1995). It relies highly on Nonaka's (1994) knowledge creation model, which conceptualizes knowledge creation as transformation of tacit knowledge into explicit knowledge and back again. A central part of the transformation is knowledge creation among individuals by combining individuals' knowledge into new knowledge (Nonaka 1994). I applied the Japanese knowledge creation approach because it enabled me to analyze PS events as knowledge creation among individuals—in my cases, the simulation participants. This enabled me to investigate RQ2. That analysis is presented in journal paper 2.

However, the knowledge creation lens also challenged me because it originally concerned organizational knowledge that often is studied through case studies of organizations. In my case studies, the units of analysis were the PS events, not the whole design organization. Consequently, I adapted the lens to study knowledge creation in the specific PS situations and not more longitudinal organizational knowledge creation initiatives. Still, the knowledge creation lens yielded a new perspective on PS in the ergonomics field.

6.3 The Knowledge Transfer and Integration Lens

The knowledge transfer and integration lens also originates from the knowledge management field (see section 6.2). The knowledge transfer and integration approach can take two forms. The first is related to information management in which transfer of knowledge is a linear process between a sender and a receiver (Yakhlef 2007; Kumar & Ganesh 2009; Gupta & Govindarajan 2000). The second views knowledge transfer and integrations as a less linear process that depends on contexts. This means that the receiving actors interpret and transform the knowledge according to their own context, background and experiences (Yakhlef 2007; Liyanage et al. 2009; Gherardi & Nicolini 2000). I have applied the second form of knowledge transfer and integration as theoretical lens, which enables me to view the activities subsequent to the PS events as knowledge transfer from the simulation context to the work system design context and integration by designers interpreting and transforming the knowledge.

This second form of knowledge transfer and integration is based on principles from actor network theory, which posits that materials and objects have just as important a role in social process as human actors (Latour 2005). Objects and actors are linked in a network, in which the links are intermediaries that circulate between the actors (Callon 1991; Gherardi & Nicolini 2000). Intermediaries can take the form of objects or actors, both embedding knowledge (Gherardi & Nicolini 2000; Callon 1991). Therefore, the circulation of these intermediaries is also transfer of knowledge in the network because the actors interpret and transform the knowledge in accordance with their specific context. The concept of intermediaries enabled me to identify actors and objects, transferring ergonomic knowledge from the PS context to the work system design context. Furthermore, the concept enabled me to analyze the interpretation and transformation of the received knowledge. This enabled me to investigate RQ3. The analysis is presented in journal paper 3.

However, the knowledge transfer and integration lens also challenged my empirical foundation, especially in relation to analysis of knowledge integration. The integration of the transferred knowledge took place in several situations in the long design process. Because building design processes take several years, I was not able to analyze how the transferred knowledge was continually integrated. Therefore, I adapted the theoretical lens to focus solely on the transition between the PS events and the design processes and the initial integration initiatives of the transferred knowledge.

6.4 Reflections on theoretical lenses

The theoretical lenses enabled me to focus on certain aspects of the empirical data. During the study, I considered applying other theoretical lenses, e.g., power theories and learning theories that would have highlighted other aspects of the PS method. Power theories could have shown negotiations, alliances and hierarchical power taking place in the PS events. Learning theory could have shown the participants' learning outcomes of the PS events and how they would have applied this in their existing and new work systems. However, the data collected did not show power relations as a central element and were not suitable for analysis of individual learning because the focus was on the collective PS events. Thus, the applied theoretical lenses both have possibilities and limitations.

7. CASE DESCRIPTIONS

In this section, the three cases of the study are described to supplement the introduction in Section 1. The case descriptions are organized in relation to the three PS frames.

7.1 CASE 1: TABLE-TOP SIMULATIONS

7.1.1 THE EXISTING WORK SYSTEM

The existing work system was the gynecological outpatient department at a major hospital in the capital region of Denmark. The existing department was in temporary pavilions and was expected to move into a new building planned as a part of an extension of the existing hospital. The extension process started in 2010 and is expected to be finished in 2017. The work in the existing work system focused on examination of gynecological patients directed from general practitioners. Patient examinations were carried out by physicians and nurses working in pairs. Medical secretaries were responsible for patient records and administrative tasks. The health care employees participating in the PS event described the ergonomic challenges of the existing work system as inefficient continuity of patient care, lack of time for experienced physicians to supervise less experienced physicians, and delays in writing patients' records.

7.1.2 THE PARTICIPATORY SIMULATION EVENTS

The PS events of the case were part of a health care innovation project managed by employees from the regional innovation center. The purpose of the innovation project was to test the participatory simulation method in health care innovation. The gynecological outpatient department volunteered to take part in the project to contribute to the design of the new department. The project group was composed of researchers in ergonomics, lean and clinical simulation, consultants from an engineering consultancy and an ergonomics consultant from the hospital. This group initiated fieldwork and other participatory methods to analyze the existing work system. The analysis was the foundation for the PS events. The events were based on a table-top model consisting of cardboard boxes representing future examination rooms and LEGO figures representing future employees and patients (Figure 16). The department management selected the participating employees based the criteria of having representatives from each employee group: physicians, nurses and secretaries. The PS events were facilitated by a researcher in medical simulation and partly by the researchers in ergonomics and lean.

Figure 16: The table-top models applied in the simulation.

Each PS event was carried out in three phases. The first involved the participants proposing a department layout by configuring the cardboard boxes. The second involved the participants engaging in simulations by enacting scenarios using the LEGO figures. The third was a debriefing in which the simulation participants reflected on insights that led to reconfiguration of the cardboard boxes, triggering new scenario acting. The outcome of the simulations was documented as notes and sketches that were included in reports describing the project to other work system designers and other regional innovation centers (for more details on the PS events, see journal papers 1 and 2).

7.1.3 THE WORK SYSTEM DESIGN PROCESS

The work system design process involved designing and planning the new gynecological department. The outcome of the PS events was presented to the architects. Members from the project group stated that at the time of the presentation, the design process was approaching the late design phases. Furthermore, the design proposal that emerged from PS outcome was significantly different than the architects' concept. Consequently, integration of the PS outcome in the new department design was not obtained. However, the PS outcome did affect organizational aspects of the work. PS participants explained that the organizational aspects were communicated to the department management and parts of this were integrated into the work practices, e.g., initiatives enabling patients to attend different examinations on the same day, which improved work practices and continuity of care.

7.2 Case 2: Full-scale mock-up simulations

7.2.1 The existing work systems

The existing work systems were two existing hospitals and three smaller clinics, all in the countryside of Denmark. The intention was that these hospitals and clinics were going to merge into a new major hospital. The design process started in 2011, and the hospital is expected to be finished in 2019. I concentrated on the design of the first part of the hospital. Employees described the ergonomic challenge at the existing hospitals and clinics as mainly related to the scattering of competencies between the hospitals and clinics, resulting in low continuity of care because the patients were switching between the hospitals and clinics. Furthermore, the workspace and technologies were out of date, resulting in a difficult work environment. Therefore, the goal was to build a new hospital with new technologies and facilities and a central emergency department, including all relevant competencies at one place.

7.2.2 The participatory simulation events

PS events of the case took place in an innovation center located in a former farm stable that was bought by the region to secure land for the new hospital. The stable was slightly renovated to provide mock-up facilities. The foundation for the PS events was architectural blueprints with design proposals for the future rooms in the new hospital. By applying chipboard walls and foam blocks, the proposed rooms were built as full-scale mock-ups to be tested through PS (Figure 17). Since 2011, around 35 rooms have been tested as full-scale mock-ups. The PS events were facilitated by two employees from the project owner organization, one with a nursing background and one with an ergonomics background. The participants were selected from a user consortium of managers, employees and ergonomics representatives from the existing hospitals and clinics.

The studied PS events consisted of three phases. The first was an introductory meeting at which the proposed room design was presented. This presentation fostered discussions of ergonomic challenges of the proposed design that led to development of work scenarios. The second phase was the testing of the room through simulation and discussion of the identified scenarios. The simulation resulted in participants formulating design specifications and suggesting redesign proposals by which the mock-ups were adjusted. In the third phase, facilitators summed up the outcomes of the simulation. During the PS events the facilitators took notes and created quick sketches of the re-design proposals to document the PS outcome. The notes and the sketches were transferred to the designers through a shared database (for more details of the six PS events, please see journal papers 1, 2 and 3).

Figure 17: The full-scale mock-ups in the innovation center.

7.2.3 The work system design process

The PS events I observed were some of the last events, and therefore they contributed to the late work system design phases: project proposal and detailed design. The work system design process was divided between the project owner's organization and the consulting designers. The designers did the specific design, and actors in the project owner’s organization were continual involved in design decisions. At the time of the study, the consulting designers consisted of two engineering companies and two architectural companies. Designers and managers in the work system design process describe the PS outcome as one out of several inputs to the design (for more about the transfer and integration of the PS outcome, please read journal paper 3).

7.3 CASE 3: THE CASE OF BLUEPRINT SIMULATIONS

7.3.1 THE EXISTING WORK SYSTEM

The existing work system that was going to be renewed was the intensive care unit (ICU) at a smaller hospital in the countryside in Denmark. The existing ICU was going to move into renovated facilities in another building. The ICU takes care of highly critical patients who are often connected to life support. Each patient was assigned a nurse, and several assistants supported the nurses. Physicians participated in ward rounds every day to make treatment decisions, and occupational therapists provided rehabilitation. Only a few medical secretaries were located in the ICU. ICU management described the ergonomic challenges of the existing work system as risk of infections between the patients, work postures for the nurses because of packed bedrooms and organization of work due to constant monitoring of patients. The purpose of the renovated facilities was to introduce single bedrooms to lower risk of infections and provide more room for appropriate work posture, including technology to support the work organization.

7.3.2 THE PARTICIPATORY SIMULATION EVENTS

PS events were part of a consulting initiative of the regional innovation center. The concept was based on architectural blueprints printed on oilcloth combined with LEGO figures and bricks (Figure 18). The idea was that after the PS events, the employees could take the blueprint to the lunch room at the existing ICU and eat their lunch on the oilcloth to become more familiar with it. The goal of the PS events was to involve all nurses, occupational therapists, assistants and medical secretaries from the ICU. The PS events were facilitated by the regional consultant and the charge nurse of the ICU. The nurse in charge of work practice development and the regional consultant prepared five scenarios for the PS events.

Each PS event was carried out in three phases. The first began with an introduction exercise in which participants obtained an overview of the blueprint. The second introduced scenarios in the form of case stories that were solved through discussions and simulation using the LEGO figures. The simulation often resulted in proposal of new organization in the new ICU. The third phase summed up insights obtained from the simulations. Participants took turns taking notes to document the outcome of the PS. The notes were collected by the ICU management after the PS events (read more about the four PS events in conference paper 2 and journal paper 2).

Figure 18: The blueprint simulation.

7.3.3 THE WORK SYSTEM DESIGN PROCESS

The purpose of the PS events was to contribute to the last phase of the work system design process. Moving the existing ICU into the new ICU facilities was planned to occur a couple of months after the PS events. Therefore, the outcome of the PS was not about the physical space but mainly about organizational aspects of the new work system. ICU management looked through the notes from the PS events and prioritized the initiatives for designing new work procedures and organization to support the new workspace. The initiatives included a new role for the coordinating nurse and new work practices for ward rounds. The simulation outcome also resulted in establishment of three working groups that assisted in implementation of the initiatives in the new ICU.

8. FINDINGS AND RESULTS

The findings and results of the study are included in three conference papers and three journal papers. I first introduce how the papers are related to the three research questions and the three PS frames. Afterward, I present short summaries of each paper. The papers are included in Appendices E to J.

8.1 RELATIONS OF THE PAPERS

The papers relate to the three research questions and the three PS frames (Figure 19). The conference papers were forerunners of the journal papers. RQ1 and RQ2 concentrated on the PS events in the second PS frame. Therefore, the related conference and journal papers are also positioned in this frame. RQ3 concentrated on the transition between the second and third PS frames. Therefore, the related conference and journal papers are also positioned across these frames.

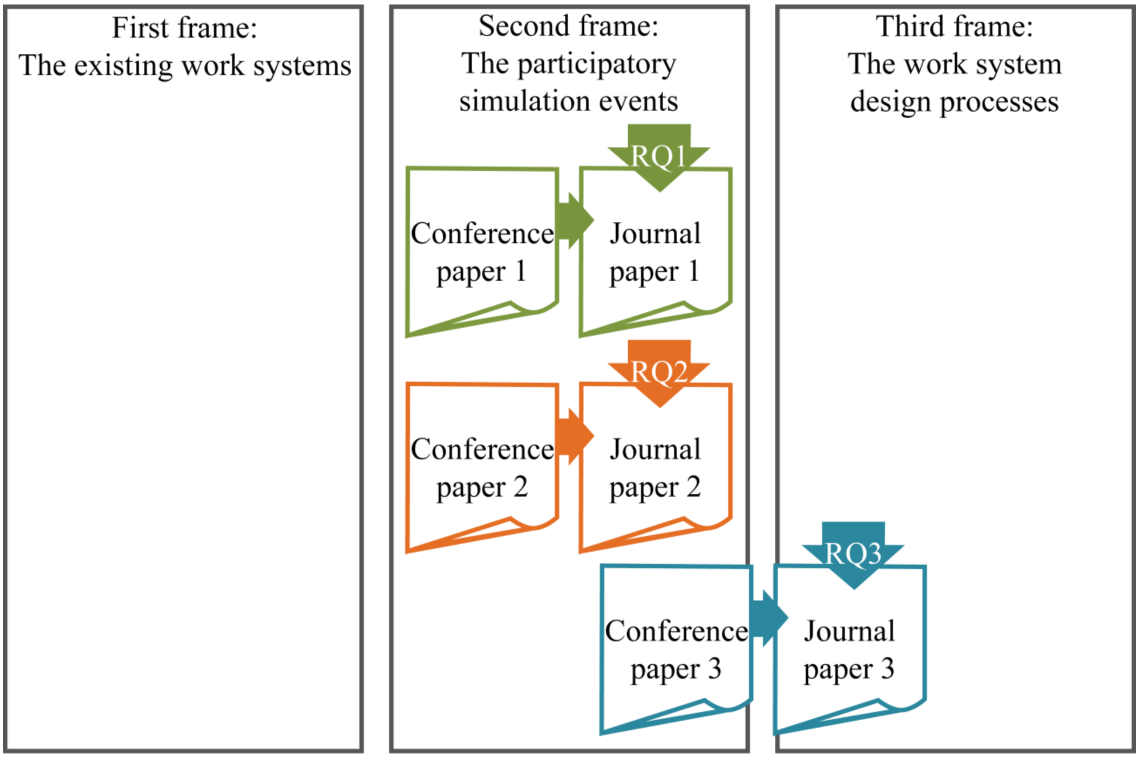

Figure 19: The three conference papers and three journal papers in relation to the three research questions and the three PS frames.

8.2 CONFERENCE PAPER 1

Title	Simulation in full-scale mock-ups: An ergonomics evaluation method?
Published	Andersen, S. N., & Broberg, O., 2014. Simulation in full-scale mock-ups: an ergonomics evaluation method? In O. Broberg et al., eds. *11th international symposium on human factors in Organisational Design And Management & 46th annual Nordic Ergonomics Society conference*. Copenhagen, pp. 793–798
Included in	Appendix E
Research aim	Explores how full-scale mock-up simulation not only is a method for testing design concepts but also an ergonomic evaluation method.
Case	Case 2: Full-scale mock-up simulations
Data	Observations and video recordings
Analysis	Mixed method analysis
Literature review	Studies of full-scale mock-ups show that the method can test room layout and work practices. However, none of the studies investigate mock-up simulation as an ergonomic evaluation method.
Findings and results	Analysis of video recordings of full-scale mock-up simulations showed that participants addressed several ergonomic conditions in relation to the future work system. However, the analysis showed that not all addressed ergonomic conditions could be evaluated by the participants. The conditions that could be evaluated resulted in adjustment of the mock-ups to improve the conditions. The mock-ups were most supportive when evaluating ergonomic conditions related to work posture and room layout. This was mainly because the mock-ups represented the room and enabled participants to test work postures.
Implications	The study showed that simulation media can represent the future work system. The evaluation possibility identified in the study indicated that the visualization may influence which type of ergonomic conditions that can be evaluated. The visualization capability varies in relation to different media, which may influence the evaluation. This finding directed my further research toward the analysis presented in journal paper 1.

8.3 JOURNAL PAPER 1

Title	Participatory ergonomics simulation of hospital work systems: The influence of simulation media on simulation outcome.
Published	Andersen, S. N., & Broberg, O., 2015. Participatory ergonomics simulation of hospital work systems: the influence of simulation media on simulation outcome.*Applied Ergonomics*,51,pp.331–342.
Included in	Appendix F
Research aim	The aim is to analyze how simulation media attributes in the form of fidelity and affordance, may influence the capability to identify and evaluate ergonomic conditions of hospital work systems. The study compares the simulation media attributes of full-scale mock-up and table-top simulations.
Related to RQ1	How are simulation media in participatory simulation influencing ergonomic evaluation in design of hospital work systems?
Cases	Case 1: Table-top simulations, case 2: Full-scale mock-ups
Data	Observations and video recordings
Analysis	Mixed method analysis
Literature review	Studies address simulation media attributes in the form of fidelity and affordance. However, how these media attributes influence the outcome of simulation in the form of ergonomic identification and evaluation has received little attention.
Theoretical lens	The work system lens
Findings and results	The analysis reveals the ergonomic conditions participants identified. In the table-top simulations, participants identified ergonomic conditions related to the future *organization* of work. In the full-scale mock-up simulations, participants identified ergonomic conditions in relation to the future *space* and application of *technologies and tools*. However, the participants were not able to evaluates all identified ergonomic conditions. The simulation media attribute in the form of fidelity and affordance influenced the evaluation possibility. The conditions participants were able to evaluate were represented by the simulation media to a high level of fidelity and affordance. The attributes varied between the two simulation media, and therefore, they supported evaluation of different ergonomic conditions.
Implications	The study showed that varying media attributes result in simulation media being able to support different ergonomic evaluations. The study emphasizes the importance of selecting simulation media in accordance with the desired ergonomic evaluation. The medium should have a high level of fidelity and affordance in relation to the parts of the future work system to be evaluated.

8.4 CONFERENCE PAPER 2

Title	The process of participatory ergonomics simulation in hospital work system design
Published	Andersen, S. N., 2016. The process of participatory ergonomics simulation in hospital work system design. In *Proceedings of International Design Conference, Design*, pp.1825–1834.
Included in	Appendix G
Research aim	The study investigates the interrelations of four participatory design perspectives with the aim of proposing a framework describing the process of PS in hospital work system design.
Cases	Case 1: Table-top simulations, case 3: Blueprint simulation
Data	Observations and interviews
Analysis	Qualitative analysis
Literature review	Studies have addressed four perspectives of participatory design processes: visualization, experimenting, participants' contribution and collaboration. The interrelations of these perspectives have attracted little research attention.
Findings and results	From the four perspectives of participatory design, five interrelated elements are identified as the process of PS. *Experimenting* is the central element of the PS process. Here the participants engaged in experiments on how to design the future work system. The elements, *simulation media interaction* and *work experience sharing* are resources for the experimenting. The *experimenting* had a close relation with the element of *reflecting*, in which participants realized and evaluated ergonomic consequences of their experiments. This led to the last element in which participants *proposed new designs* in the form of design specifications as the PS outcome.
Implications	The study indicates that the PS process is constituted of several interrelated elements in the form of activities in which the participants engage. The process is directional toward participants proposing new design and formulating design specifications for solving realized ergonomic challenges. This process of creating joint design proposals and specifications can be related to the process of creating new knowledge. This perspective led to development of journal paper 2.

8.5 JOURNAL PAPER 2

Title	A framework of knowledge creating processes in participatory simulation of hospital work system
Published	Andersen, S. N., & Broberg, O., 2016. A framework of knowledge creation processes in participatory simulation of hospital work systems. *Ergonomics* doi:10.1080/00140139.2016.1212999
Included in	Appendix H
Research aim	This study aims to develop a framework describing the process of how ergonomic knowledge is created in PS. The intention is that the framework can support planning and facilitation of PS.
Related to RQ2	How is ergonomic knowledge created in participatory simulation in design of hospital work systems?
Cases	Case 1: Table-top simulations, Case 2: Full-scale mock-up simulations and Case 3: Blueprint simulations
Data	Video recordings
Analysis	Mixed methods analysis
Literature review	Research has mainly focused on the PS outcome and not the process of creating it. By introducing a knowledge creation perspective, the process of creating the outcome can be analyzed. The outcome is ergonomic knowledge.
Theoretical lens	The knowledge creation lens
Findings and results	From analysis of the three cases, a PS framework is proposed based on five main activities and eight sub-activities. Through sequences and overlaps, the activities describe the knowledge creation process of PS. The most frequently occurring sequences showed that the knowledge creation process included knowledge externalization and knowledge combination. These led to a joint creation of ergonomic knowledge in the form of design specifications formulated by the PS participants.
Implications	The PS framework supports planning of PS by revealing the activities constituting the knowledge creation process. Thus, the planner knows which activities to plan for. The PS framework supports facilitation of PS by revealing the connections between the activities constituting the knowledge creation process. The connections show which activities form sequences leading to knowledge creation. Thus, the PS facilitator knows which activities to encourage to create the best possibility for ergonomic knowledge creation. Therefore, the PS framework reveals the previously hidden steps of the PS process.

8.6 Conference paper 3

Title	The role of knowledge objects in participatory ergonomics simulation
Published	Andersen, S. N., 2015. The role of knowledge objects in participatory ergonomics simulation. In *Proceedings 19th Triennial Congress of the IEA.*
Included in	Appendix I
Research aim	The aim is to investigate the role of objects applied in generating ergonomic knowledge in PS and transfer of ergonomic knowledge to the design process.
Cases	Case 2: Full-scale mock-up simulations
Data	Observations, video recordings and interviews
Analysis	Qualitative analysis
Literature review	Studies show that knowledge sharing can benefit from the application of objects. However, how objects can play a role in ergonomic knowledge generation in PS and bridge the gap between PS and the design process has attracted little attention.
Findings and results	Several objects were identified to play a role in the generation and transfer of knowledge. Architectural blueprints transferred knowledge from the design process into the PS. The blueprints fostered creation of full-scale mock-ups, supporting knowledge generation during PS. The generated ergonomic knowledge was documented as notes and sketches, taking the role of knowledge transferring objects from PS to the design process. The identified objects changed characteristics during the knowledge generation and transfer by being either "open" or "closed." These changes were due to designers, simulation facilitators and simulation participants interpreting the objects and the knowledge the objects represented.
Implications	The paper indicates that the transfer of knowledge over the gap between the PS setting and the design setting is a complex task. The transfer is influenced by interpretations. Knowledge transfer, identified in this paper, was the foundation for further study of knowledge transfer and integration into the work system design, as presented in journal paper 3.

8.7 JOURNAL PAPER 3

Title	Ergonomics knowledge transfer from participatory simulation and integration into hospital design
Submitted	Andersen, S. N. & Broberg, O. *Human Factors and Ergonomics in Manufacturing and Service Industries*
Included in	Appendix J
Research aim	The study aims to investigate the mechanisms behind ergonomic knowledge transfer from PS events to hospital design and integration into the design. The study focuses on investigating how intermediaries can take part in knowledge transfer and integration.
Related to RQ3	How is ergonomic knowledge from participatory simulation transferred to hospital work system design processes and integrated into design?
Cases	Case 2: Full-scale mock-up simulations
Data	Observations, interviews and documents
Analysis	Qualitative analysis
Literature review	Research on ergonomic knowledge transfer and integration focus on transfer of knowledge from ergonomics researcher to practice or from ergonomists to designers. However, how ergonomic knowledge created in PS is transferred to work system designers and integrated in design has attracted little attention.
Theoretical lens	The knowledge transfer and integration lens
Findings and results	The analysis revealed PS participants with intermediary abilities acting as boundary spanners between the PS and the work system design process. Furthermore, the sketches produced as the PS documentation were identified as intermediary objects, codifying the created knowledge and transferring it to the design process. The designers received the intermediary objects and integrated the codified knowledge by revising the architectural blueprints. However, not all of the transferred knowledge were integrated. The lack of integration was not directly related to the form of the knowledge. Instead, the integration was influenced by design constraints that led the designers to interpret and transform the ergonomic knowledge to make it adaptable with the design situation.
Implications	The study shows that transfer of knowledge from PS to the design process and integration in design is crucial for PS events to have a design impact. Therefore, the paper suggests that when planning PS, the focus should not only be on facilitation and execution of PS, but also on the subsequent and complex process of knowledge transfer and integration.

9. A PARTICIPATORY SIMULATION TAXONOMY

One part of the PhD study was to develop a PS taxonomy, a synthesis of the literature review, the three cases and the papers of the study. The aim of the taxonomy was to support 1) researchers in analyzing and categorizing PS and 2) practitioners in planning and facilitating PS. In this section, I present the development of the taxonomy and reflect on how it can be applied in research and practice.

Few studies within the ergonomics field have investigated PS as a work system design method (Daniellou 2007; Barcellini et al. 2014), and the elements of PS have attracted little attention. To provide an overview of the elements of PS and extend the knowledge base, I developed a PS taxonomy. Within the ergonomics field, taxonomies have previously been developed for classifying other phenomena into categories (Sheridan 2014; Patel et al. 2012; Greco et al. 2013; Wilson et al. 2005). Therefore, taxonomies are known classification methods in the ergonomics field, but no existing taxonomy classifies the PS phenomenon and provides an overview of the PS elements.

9.1 CLASSIFYING PARTICIPATORY SIMULATION

I classified the PS method based on the literature review in Section 4, the three cases presented in Section 7 and the papers presented in Section 8. I conducted the classification in three steps (Figure 20). In the first step, I compared the literature, the three cases and the findings in the papers. From this comparison, I identified six categories that characterized six elements of PS across this study. In the second step, I examined the literature and the parts of my study related to the six categories, and I identified 14 subcategories. In the third step, I examined the subcategories and identified variations of them. I describe the six categories and the 14 subcategories in the following sections.

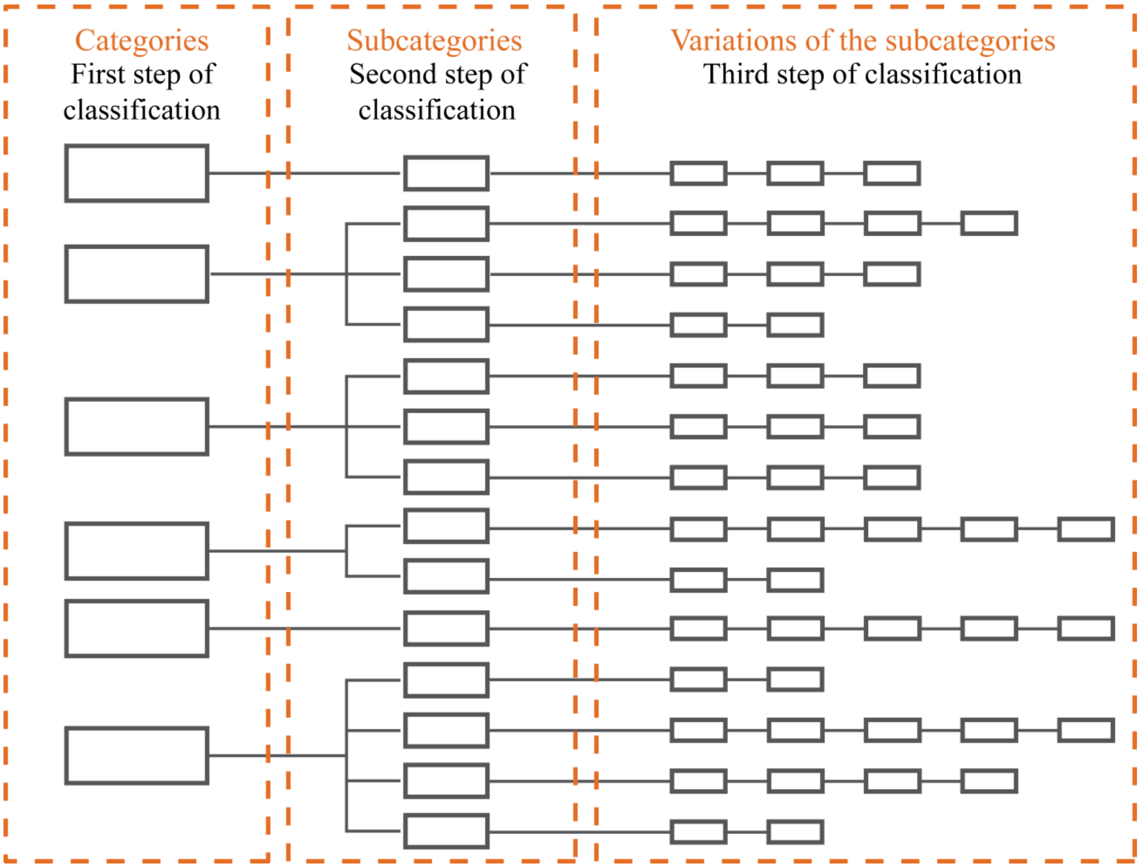

Figure 20: Overview of the three steps of classifying the PS method across the literature review, the three cases, and the findings from the six papers of this study.

9.1.1 Simulation outset

In literature	Research shows that simulation outset often takes the form of an initial work system design proposals (Daniellou 2007; Barcellini et al. 2014). However, the initial design can be proposed by different actors, e.g., managers (Ruohomäki 2003), designers (Persson et al. 2014; Watkins et al. 2008; Koningsveld et al. 2005) or ergonomists (Österman et al. 2016; Hallbeck et al. 2010; Koningsveld et al. 2005; Seim & Broberg 2010).
In the three cases	The three cases show that simulation outset is proposed by different actors. In the case of the table-top simulations, the outset was design proposals by the participating health care employees. In the cases of full-scale mock-up and blueprint simulations, the outset was design proposals by designers.

The literature and cases show that simulation outset can be proposed by different actors and may therefore have different focus. I see this outset focus as a possible influencer on PS events, and therefore I argue that the simulation outset is an element to consider when analyzing and planning PS. Therefore, I defined the taxonomy category, *simulation outset*, with the subcategory, *actor proposing outset*.

9.1.2 Simulation medium

In literature

Studies have listed several different types of simulation media with different capabilities (see Section 3.1 and Appendix A). Furthermore, research shows that physical media support simulation participants interacting directly with the medium, e.g., by grasping and moving parts (Persson et al. 2014; Ruohomäki 2003; Broberg & Edwards 2012; Seim & Broberg 2010; Bligård et al. 2014; Våland & Georg 2014). Furthermore, the literature shows that computer-based media often needs a professional operator, and therefore the participating employees cannot directly interact with the medium (Persson et al. 2014; Davies 2004; Paquet & Lin 2003; Sundin & Medbo 2003).

In the papers of the thesis

The findings in conference paper 1 and journal paper 1 show that simulation media attributes, in the form of fidelity and affordance, influence the types of ergonomic conditions that can be evaluated in PS. Simulation media have varying attributes and are therefore capable of supporting evaluation of different ergonomic conditions, e.g., conditions related to organization or the physical space. Additionally, conference paper 2 and journal paper 2 show that simulation participants' direct interaction with the simulation media is central to the knowledge creation process of PS.

The research and the papers of this study show that the simulation medium influences the PS events. Therefore, the simulation medium is an element to consider when analyzing and planning PS. I included the taxonomy category, *simulation medium* and identified three subcategories, *type of medium*, *ergonomic conditions for evaluation* and *participant interaction with medium*.

9.1.3 Simulation scenarios

In literature

The research has not focused on the simulation scenarios applied in PS. Only Daniellou (2007) and Barcellini et al. (2014) have acknowledged the scenario as a component of PS. However, the literature on scenarios in design shows they influence idea generation (Carroll 2000; Suri & Marsh 2000). Therefore, scenarios might well influence PS.

In the three cases

The three cases of this study show different types of scenarios. The table-top simulations were based on fixed scenarios that were applied as manuscripts for scenario acting. Here the scenarios were prepared by the management and facilitators, and the objective was to simulate existing work and unanticipated events. The full-scale mock-up and blueprint simulations were based on more open scenarios applied to start the simulation and continually developed during the simulation. The objective was to simulate future work. The scenarios in the full-scale mock-up simulations were prepared by the participating health care employees, while the scenarios in the blueprint simulations were prepared by management and a facilitator.

In the papers of the thesis

Journal paper 2 shows that simulation scenarios are central in the knowledge creation activity in which participants experiment with future work system design.

Even though the PS literature has not concentrated on scenarios, the cases and papers of this PhD study show that scenarios are a central PS element. Therefore, I argue that scenarios have to be considered when analyzing and planning PS, and I included the taxonomy category *simulation scenarios*. Additionally, I identified the following subcategories, *scenario type*, *scenario objective* and *actor preparing scenario*.

9.1.4 Simulation facilitation

In literature

PS studies have not focused on facilitation. However, literature on simulation as a teaching method shows that facilitation style influences educational profit (Clapper 2014). Therefore, the facilitation might well influence PS.

In the three cases

The three cases have different types of facilitators, e.g., from the project owner's organization, managers or consultants. Furthermore, the facilitators applied different facilitation styles. The facilitators of the full-scale mock-ups and blueprint simulations applied an open facilitation style by encouraging the participants to lead the direction of the PS. The facilitator in the case of table-top simulation applied a more closed facilitation style by constantly directing and monitoring the progression of the PS.

Even though the PS research has not focused on facilitation, facilitation might influence the PS. Therefore, I argue that facilitation is a relevant element to consider when analyzing and planning PS. I included the taxonomy category *simulation facilitation* and identified two subcategories, *facilitator* and *facilitation style*.

9.1.5 Simulation participants

In literature	PS studies have not focused on the influence of simulation participants. Only few studies have acknowledged that participants bring their individual knowledge to the PS event (Garrigou et al. 1995; Béguin 2003; Daniellou 2007).
In the papers of the thesis	Conference paper 2 and journal paper 2 show that the participants sharing their knowledge is a central knowledge creation activity in PS.
In the three cases	The three cases involved different types of participants, e.g., employees, designers and managers. These different types of participants have different individual knowledge.

Therefore, simulation participants and their knowledge might influence the PS. I argue that simulation participants are an element to consider in analyzing and planning of PS. I included the category, *simulation participants,* in the taxonomy and the subcategory, *type of participants*.

9.1.6 Simulation documentation and communication

In literature	Few PS studies have focused on subsequent documentation and communication of the PS outcome in the form of created ergonomic knowledge. Documentation and communication are related to transfer and integration of ergonomic knowledge into work system design. Studies on ergonomic integration in general and not as a part of PS show that ergonomic knowledge can take different forms, e.g., specifications or recommendations (Wulff et al. 1999b; Broberg 2007; Campbell 1996; Kim 2010; Skepper et al. 2000). Studies on knowledge transfer and integration show that knowledge can be documented in different ways and can be

transferred by intermediaries (Gherardi & Nicolini 2000; Conceição et al. 2012; Hall-Andersen & Broberg 2013).

In the papers of the thesis

The intermediary ability of objects and actors in conference paper 3 and journal paper 3 are means of transferring ergonomic knowledge created in PS to work system design processes. Furthermore, the papers show how important the documentation and communication of the ergonomic knowledge is to have an actual design impact.

In the three cases

The three cases show that different actors can document the created ergonomic knowledge. In the table-top simulations and the full-scale mock-up simulations, the facilitators documented the created knowledge, while in the blueprint simulations, the participating employees did the documentation.

The documentation and communication influence the transfer and integration of the simulation outcome in design. Therefore, I argue that documentation and communication are elements to consider when analyzing and planning PS. I included the taxonomy category *simulation documentation and communication* and identified four subcategories, *type of communicated knowledge*, *documentation*, *documenting actors* and *means of transfer*.

9.2 THE PARTICIPATORY SIMULATION TAXONOMY

Table 12 shows the defined categories, subcategories and variations of the PS taxonomy. To show how the taxonomy can help in analyzing and categorizing PS, I have indicated the three cases of the study in parentheses.

Simulation outset	**Actor proposing outset**	Employees (Case 1)	Designers (Case 2, 3)	Managers	
Simulation medium	**Type of medium**	Abstract models based on Post-its or other table-top models (Case 1)	Scale models based on 2D or 3D drawings or models (Case 3)	Full-scale models based on 2D or 3D models or virtual reality (Case 2)	Discrete event simulation and digital human modeling
	Ergo. conditions for evaluation	Conditions in relation to organization (Case 1)	Conditions in relation to technologies and tools (Case 2)	Conditions in relation to physical space (Case 2, 3)	
	Participant interaction with medium	Direct interaction and manipulation of the medium by participating employees (Case 1, 2, 3)	Interaction and manipu-lation by technical professional operator		
Simulation scenarios	**Scenario type**	Open applied as start of discussions and acting (Case 2, 3)	Fixed applied as manuscript with time defined tasks for acting (Case 1)	Unanticipated event in the form of dis-turbances and accidents (Case 1)	
	Scenario objective	Simulate existing work practice (Case 1)	Simulate intended future work practices (Case 2, 3)	Simulate unanticipated events (Case 1, 3)	
	Actors prepa-ring scenario	Employees (Case 2)	Facilitators (Case 1, 3)	Managers (Case 1, 3)	

Simulation facilitation	Facilitator	Ergonomist (Case 2)	Management (Case 3)	Designers (Literature review)	Project owner (Case 2, 3)	Consultants (Case 1, 3)
	Facilitation style	Open—the facilitator encourages participants to direct and lead (Case 2, 3)	Closed—the facilitator closely monitors the event (Case 1)			
Simulation participants	Types of participants	Work environment representative (Case 2)	Lead workers, employees with specific knowledge and often engaged in initiatives on existing workplace (Case 1, 2)	Randomly selected employees (Case 3)	Project owner management (Case 1, 2)	Designers in the form of engineers and architects (Case 2)
Simulation documentation and communication	Type of PS outcome	Design specifications in the form of specific and tangible design proposal (Case 1, 2)	Design recommendations in the form of more intangible design focus points (Case 1, 2, 3)			
	Documentation	Sketches (Case 1, 2)	Notes (Case 1, 3)	Video recordings	Pictures	Descriptions (Case 2)
	Documenting actors	Employees (Case 3)	Management	Designers (Case 2)	Facilitator (Case 1, 2)	
	Means of transfer	Intermediary actors in the form of actors transferring knowledge (Case 2)	Intermediary objects in the form of objects transferring knowledge (Case 1, 2, 3)			

Table 12: The PS taxonomy. The parentheses indicate the classification of the three cases applied in this study.

9.3 Application of the Taxonomy in Research

The first aim of the PS taxonomy was to support researchers in analyzing and categorizing PS activities. The taxonomy can help categorize PS activities and thus provides a frame for analyzing differences and commonalities of PS events. To demonstrate the PS taxonomy, I have categorized the three cases of the study by indicating them in parentheses in the taxonomy in Table 12. Furthermore, to demonstrate the analysis potential of the taxonomy, I will provide examples of differences and commonalities identified from the case classification.

9.3.1 Identified differences

From categorization of the three cases several differences were revealed. I see a main difference related to the category, *simulation medium*, and the subcategory, *type of medium*, showing that the three cases apply three different simulation media. I already recognized this difference when selecting the cases (see Section 5.2.2). However, the classification of the three cases show further differences, e.g., the categories *simulation scenario*, *simulation facilitation* and *simulation participants* all show differences between the three cases. The differences were not clear to me in the case selection in Section 5.2.2. They became clear when I developed and applied the PS taxonomy to the three cases. Therefore, the classification of the cases demonstrates that the PS taxonomy can provide an overview of the differences between PS activities.

9.3.2 Identified commonality

The categorization also showed commonalities between the three cases. I see a main commonality in the category *simulation medium* and the subcategory *participants interacting with medium*. The three cases all included media that allowed participants to directly manipulate and interact with the medium. This commonality was not clear to me before I developed and applied the PS taxonomy to the three cases. Therefore, the classification of the cases demonstrates that the PS taxonomy can provide an overview of the commonalities between PS activities.

9.4 Application of the Taxonomy in Practice

The second aim of the PS taxonomy was to support practitioners in planning and facilitating PS activities. However, the current form of the taxonomy provides an overview of the PS elements but does not show the consequences, advantages and challenges of the different variants. Yet, this is important for practitioners to know when planning and facilitating PS events. To show the consequences, I developed a short brochure and four guides for practitioners as supplements to the PS taxonomy. The purpose of the guides was to prepare practitioners to make deliberate and systematic decisions when planning PS. The intention was that the practitioner in this way could implement and facilitate more goal-oriented PS events aiming at designing ergonomic work systems. The guides are described in the following paragraphs, an example is illustrated in Figure 21, and all guides are included in Appendix K.

A guide for selecting simulation medium

This guide is based on the taxonomy category *simulation medium*. The guide includes questions directing practitioners to select media in relation to the specific design phase and the intended ergonomic evaluation. The ergonomic evaluation is based on the taxonomy subcategory *ergonomic conditions for evaluation*. The guide presents examples of simulation media, including their advantages and challenges, and thus illustrates the consequences of the medium selection. The simulation media examples are based on the taxonomy subcategory *type of simulation medium*.

A guide for selecting scenarios and facilitation

This guide is based on the taxonomy categories *simulation scenarios* and *simulation facilitation*. The guide includes questions directing practitioners to select the type of scenario and facilitation style in relation to the PS' purpose and the resources available for assisting in preparing the scenario. The resources are based on the taxonomy subcategory *actors preparing scenario*. The guide presents examples of scenarios, including advantages and challenges, and thus illustrates the consequences of the scenario selection. The scenario examples also include examples of facilitation based on the taxonomy subcategories *scenario type* and *facilitation style*.

A guide for selecting participants

This guide is based on the taxonomy category *simulation participants*. The guide includes questions directing practitioners to select participants in relation to the knowledge needed in the simulation and the needed abilities of the participant. The guide presents examples of participants, including advantages and challenges, and thus illustrates the consequences of the participant selection. The participant examples are based on the taxonomy subcategory *types of participants*.

A guide for selecting documentation and communication

This guide is based on the taxonomy category *simulation documentation and communication*. The guide includes questions directing practitioners to select the documentation type in relation to the expected PS outcome and the person documenting the outcome. The expected outcome and the documenting person are based on the taxonomy subcategories *type of PS outcome* and *documenting actors*. The guide presents examples of documentation, including advantages and challenges, and thus illustrates the consequences of the documentation selection. The documentation examples are based on the taxonomy subcategory *documentation*.

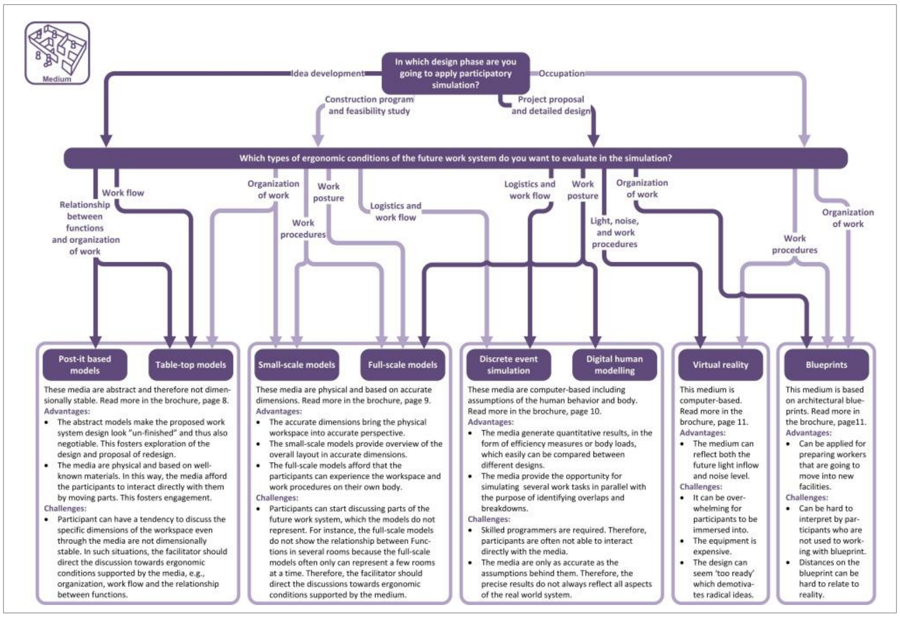

Figure 21: An overview of one of the four guides for practitioners. By answering the questions and following the arrows, the user of the guides will be directed toward possible choices in the planning of PS. See the four guides in details in Appendix K.

9.4.1 Evaluation of the taxonomy and guides in practice

To ensure the relevance of the PS taxonomy and the guides in practice, I evaluated both in a workshop with 20 practitioners. The practitioners were ergonomists, architects, engineers, process consultants and health care innovation employees who all had experience in planning and facilitating PS in designing ergonomic work systems. The workshop was scheduled for two hours. First, I introduced the PS taxonomy and the guides. I asked the participants to test the taxonomy and guides by planning a PS event in relation to one of their own current design projects. A picture from the workshop is included in Figure 22. The participants all managed to plan a PS event in accordance with the four guides. Based on the planning exercise, I asked the participants to give feedback on the form and content of the guides. Several participants acknowledged that the guides "forced" them to reflect on their choices and make deliberate and systematic decisions. I have summarized the feedback in Figure 23. The feedback provided a basis for further development of the taxonomy and guides.

Figure 22: One of the groups in the workshop comprising an engineer, an architect, and a managing nurse with experience in health care innovation.

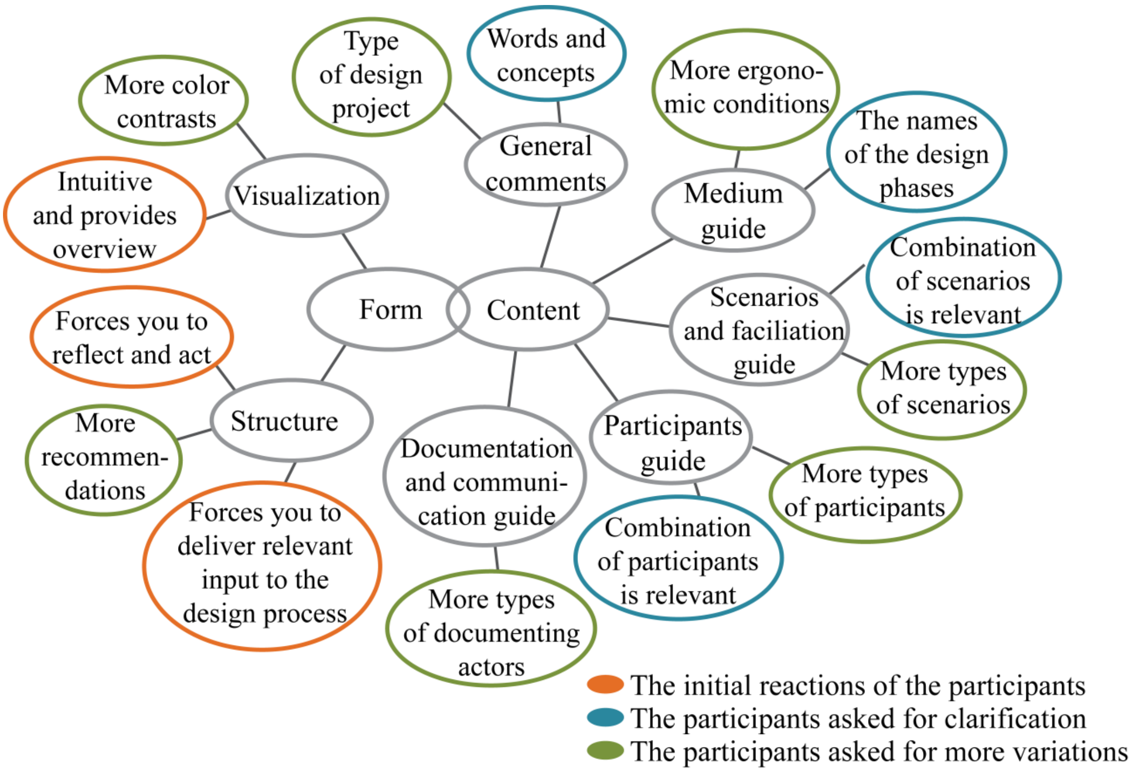

Figure 23: A mind map showing an overview of the feedback obtained.

10. DISCUSSION

In this section, I define the core findings of this study and relate these to existing research. Additional, I argue for the contribution of the core findings. In the end, I reflect on the transferability of the study and provide suggestions for further research.

10.1 THREE CORE FINDINGS

Based on the paper of the study, I have listed three core findings and the transverse PS taxonomy in Figure 24. The findings and the taxonomy will be discussed in the following sections.

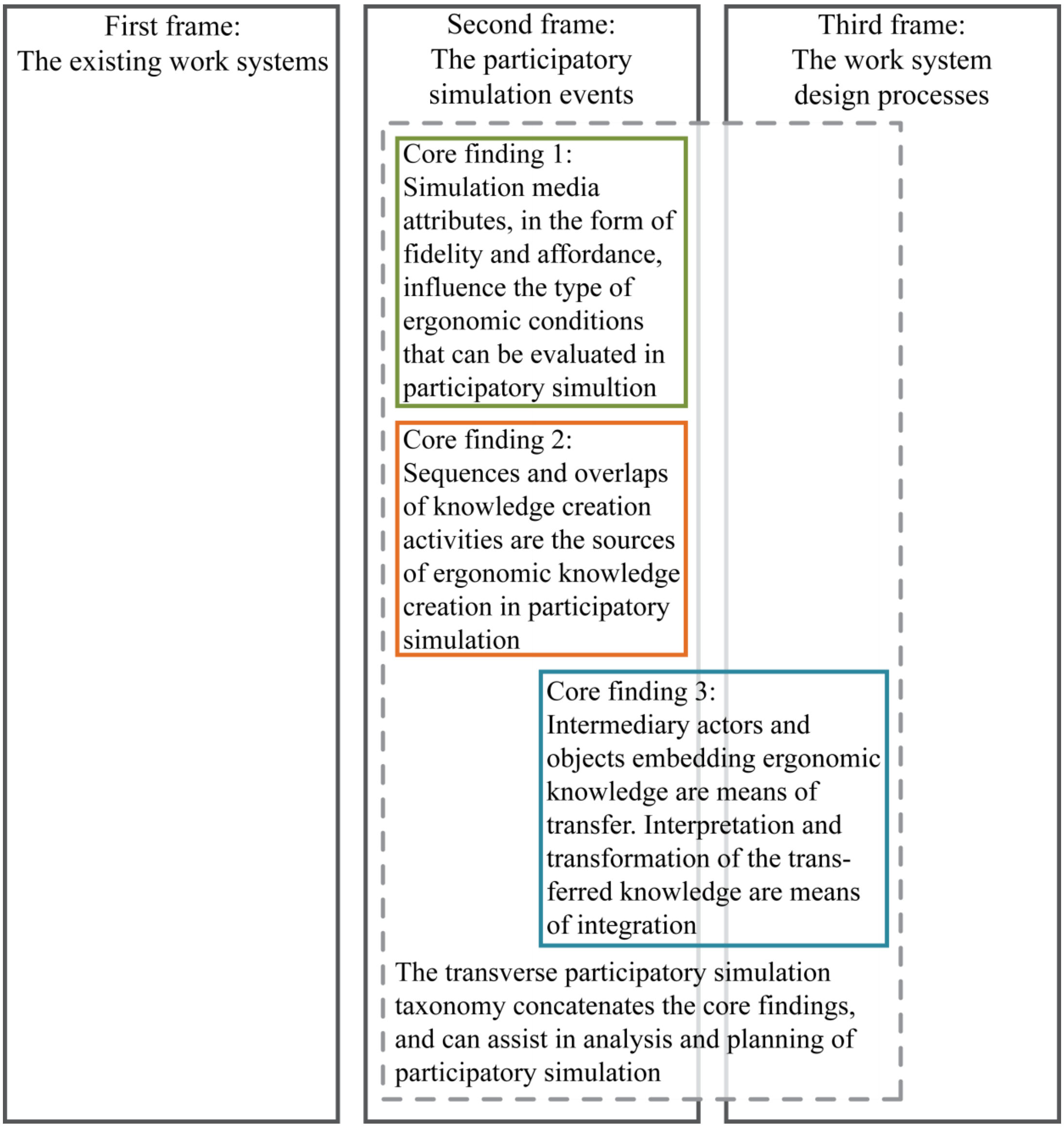

Figure 24: The three core findings of the study and the participatory simulation taxonomy in relation to the three frames of PS.

10.1.1 CORE FINDING 1

Simulation media attributes in the form of fidelity and affordance influence the type of ergonomic conditions that can be evaluated in participatory simulation.

This core finding originates from conference paper 1 and journal paper 1. Conference paper 1 showed that simulation media can support evaluation of ergonomic conditions of the future work system. Journal paper 1 took this finding further by showing that media attributes in the form of fidelity and affordance influenced the possibility of evaluation. Furthermore, journal paper 1 showed that simulation media have varying attributes and therefore support evaluation of different types of ergonomic conditions of the future work system.

The research on PS and other participatory methods has shown that simulation media have different capabilities, e.g., small scale models provide overviews (Österman et al. 2016; Seim & Broberg 2010) and full-scale mock-ups provide testing of interior and layout (Hignett et al. 2010; Villeneuve et al. 2007; Watkins et al. 2008; Paquet & Lin 2003). Furthermore, studies show that simulation media have different attributes, e.g., in relation to the degree of reality in the visualization (Hallbeck et al. 2010; Steinfeld 2004; Watkins et al. 2008; Broberg et al. 2011). How capabilities and attributes support evaluation of different ergonomic conditions is a common reflection point in the studies. However, the actual influence on the ergonomics evaluation had not before been investigated. Core finding 1 is the result of such investigation and states that fidelity and affordance are the influencing attributes in relation to which type of ergonomic conditions that can be evaluated. One type of medium seldom has high fidelity and affordance in relation to all work system areas; therefore, one type of medium cannot support evaluation of all types of ergonomic conditions. Therefore, the medium attributes' influence is important to understand to deliberately select simulation media when planning PS for evaluating future ergonomic conditions. I argue that otherwise we risk selecting simulation media that do not support evaluation of the intended ergonomic conditions. Therefore, medium selection matters in PS planning.

CONTRIBUTION OF CORE FINDING 1

First, core finding 1 introduces the terms fidelity and affordance to describe the attributes of simulation media. These terms originates from the interaction research field (e.g., Norman 2002) and have mainly been applied to cognitive ergonomics (e.g., Hall 2001; Lim et al. 2008; Turner 2005) but not to participatory ergonomics and PS. The terms bring a new perspective to participatory ergonomics and PS studies by showing the relationship between the media attributes and the ergonomic evaluation. Therefore, the media attributes of fidelity and affordance are introduced as new elements to take into account when selecting a simulation medium.

Second, the core finding connects the research that defines different capabilities of simulation media (Österman et al. 2016; Seim & Broberg 2010; Hignett et al. 2010; Paquet & Lin 2003; Villeneuve et al. 2007; Watkins et al. 2008) and the research that addresses different media attributes (Hallbeck et al. 2010; Steinfeld 2004; Watkins et al. 2008; Broberg et al. 2011). This connection shows how the media attributes influence the media's capability to support ergonomic evaluation. In this way, core finding 1 connects two research foci of PS that not previously have been connected. The connection show that medium attributes are relevant to consider for making deliberate choices when selecting simulation medium.

10.1.2 CORE FINDING 2

Sequences and overlaps of knowledge creation activities are the sources of ergonomic knowledge creation in participatory simulation.

Core finding 2 originates from conference paper 2 and journal paper 2. Conference paper 2 indicated that PS is a process of creating new joint design proposals to solve identified ergonomic challenges of future work systems. Journal paper 2 extended this finding by introducing the knowledge creation perspective, approaching PS as a process of creating new ergonomic knowledge in the form of design specifications. Furthermore, journal paper 2 introduced a process mining analysis method resulting in identification of the knowledge creation sources in the form of activities connected in sequences and overlaps.

Research on PS has highlighted benefits such as fostering innovation (Broberg & Edwards 2012) and improving work system properties that otherwise would lead to hazards or malfunctions (Daniellou 2007). Furthermore, research has shown that the outcome of PS often is employee feedback, which can function as design specifications (Barcellini et al. 2014; Broberg et al. 2011; Österman et al. 2016; Béguin 2003). In this way, the research has mainly focused on the benefits and outcome of PS and not the process of creating that outcome. The few studies that have acknowledged the process of creating the outcome have described PS as including participants' individual professional experiences, competencies and knowledge, often in a tacit form (Daniellou 2007; Garrigou et al. 1995; Norros 2014; Béguin 2003). Furthermore, PS has been identified as a potential method for converting tacit knowledge into explicit knowledge and therefore create new knowledge (Norros 2014). How the knowledge is created has not previously been analyzed in the ergonomics field. Core finding 2 is the result of such analysis, revealing that ergonomic knowledge in PS is created through sequences and overlaps of knowledge creating activities. The knowledge creation process in PS is important to understand when planning PS events to make deliberate decisions on scenarios, participants and media and to facilitate the process. I argue that without understanding the knowledge creation process, we risk blindly planning and facilitating PS events.

Contribution of core finding 2

First, core finding 2 introduces the theoretical lens of knowledge creation. Research in the ergonomics field has introduced knowledge management terms such as experiential learning and knowledge sharing (Neumann et al. 2012; Garrigou et al. 1995; Béguin 2003). However, no study has analyzed PS as a knowledge creation process. The knowledge creation lens provides a new perspective for understanding that PS is composed of knowledge creating activities. Understanding of the activities that constitute the PS process is valuable when planning PS, because the simulation medium, participants and scenarios can be selected to encourage knowledge creation activities. In this way, the knowledge creation process of PS can be supported and potentially result in creation of ergonomic knowledge that is valuable for further work system design.

Second, the core finding introduces the term process, which is not unfamiliar in work systems studies (Carayon et al. 2015; Wilson 2014; Kleiner 2006). Systems have been defined as processes of transformations (Edwards & Jensen 2014). However, process analysis methods such as process mining are rarely introduced in the ergonomics field. The process perspective and process mining analysis revealed sequences and overlaps between the knowledge creation activities in PS. Understanding of these sequences and overlaps is central when facilitating PS events, because the facilitator can therefore direct the participants to engage in activities that have shown potential for leading to creation of new ergonomic knowledge.

10.1.3 Core finding 3

Intermediary actors and objects embedding ergonomic knowledge are means of transfer. Interpretation and transformation of the transferred knowledge are means of integration.

This core finding originates from conference paper 3 and journal paper 3. Conference paper 3 focuses on transfer of the created ergonomic knowledge from the PS setting to the work system design setting. The paper shows that knowledge transfer can be supported by intermediary objects that codify the created knowledge and transfer it to the designers in the design process. Journal paper 3 elaborated on this by including intermediary actors in the analysis of knowledge transfer. Furthermore, this paper analyzes integration of the transferred knowledge into the work system design. Design constraints were identified that resulted in interpretation and transformation of the knowledge, highlighting the difficulties in integrating ergonomic knowledge in design.

Research on PS has mainly concentrated on PS' benefits and outcome (e.g., Hallbeck et al. 2010; Seim & Broberg 2010; Steinfeld 2004; Sundin et al. 2004) and not the subsequent transfer and integration of the created knowledge. Few studies of PS acknowledge the need for transfer and integration of the PS outcome into design (Barcellini et al. 2014; Broberg et al. 2011), but they do not investigate the topic. Core finding 3 is a result of such investigation and shows that intermediary actors and intermediary objects are means of transfer, and interpretation and transformation of the transferred knowledge are means of integration. This knowledge transfer and integration are crucial for PS to achieve an actual design impact. Therefore, understanding and planning of knowledge transfer and integration are just as important as planning the PS event itself. I argue that otherwise, we risk that the created ergonomic knowledge is poorly transferred and insufficiently integrated into the work system design.

Contribution of core finding 3

First, the core finding combines the concepts of intermediary objects and intermediary actors in the term intermediaries. These concepts are usually combined because they supplement each other (e.g., Gherardi & Nicolini 2000), but they have not before been applied in a combination in the ergonomics field. Ergonomic studies have either applied the concept of intermediary objects (Hall-Andersen & Broberg 2013) or the concept of intermediary actors (Seim et al. 2014). The combination of the two shows the variations of the concepts and highlights how intermediary actors and objects transfer different forms of ergonomic knowledge, e.g., actors transfer interpretations and objects transfer specifications. The intermediaries' transferring capabilities are important to understand when planning PS. In this way, actors that can take a role as intermediary actors can be invited to participate in the PS. Furthermore, a strategy for producing intermediary objects that codify the created knowledge can be planned.

Second, core finding 3 also underlines that knowledge transfer is not enough. The knowledge also has to be integrated. Several studies have investigated integration of ergonomic knowledge in design through ergonomic guidelines and standards (Broberg 2007; Campbell 1996; Conceição et al. 2012; Hignett & Lu 2009; Kim 2010; Skepper et al. 2000; Wulff et al. 1999a). These studies show that integration is influenced by several constraints. The studied ergonomic guidelines and standards were not results of participatory activities but instead were produced by ergonomists acting as experts. Therefore, ergonomic knowledge created by employees participating in PS has not previously been investigated in the ergonomics field. However, integration of ergonomic knowledge, created by employees participating in PS, proved in this study to be just as constrained and difficult as integration of guidelines developed by ergonomists. This resulted in designers interpreting and transforming the knowledge for integration into the constrained design. Therefore, when planning PS it is important to understand the design context in which the transferred knowledge is going to be integrated. This enables the PS planner to include the design constraints in the PS event and in this way target the created knowledge to the subsequent integration.

10.1.4 The transverse participatory simulation taxonomy

The participatory simulation taxonomy concatenates the core findings and can assist in analysis and planning of participatory simulation activities.

The PS taxonomy is based on the literature review, the three cases and the papers of the thesis. It was developed to support 1) researchers in analyzing and categorizing PS and 2) practitioners in planning and facilitating PS. Section 9.3 showed how the taxonomy can be applied to analyze and categorize PS activities from a research perspective, and Section 9.4 showed how the taxonomy and the supplemental guides can support planning of PS activities in practice.

CONTRIBUTION OF THE PARTICIPATORY SIMULATION TAXONOMY

Taxonomies have previous been introduced in the ergonomics field (Sheridan 2014; Patel et al. 2012; Eklund 2000). The most recognized one is the participatory ergonomics framework (PEF) (Wilson et al. 2005; Haines et al. 2002). The PEF functions as guidance and review of participatory ergonomics projects. Because PS is a participatory ergonomics method, several of the categories in the PS taxonomy relate to categories of the PEF. However, the PS taxonomy also includes categories and elements supplementing the PEF. These are, for example, simulation media, scenarios as a central part of the PS process and the subsequent knowledge transfer. These categories are essential for PS in work system design. The PS taxonomy contributes to the PEF and supplements the limited knowledge base on PS by providing a frame for categorizing and analyzing PS from a research perspective. Furthermore, the PS taxonomy together with the supplemental guides function as a tool for planning and facilitating PS events. In this way, the taxonomy also contributes to the practice of the ergonomics discipline.

10.2 TRANSFERABILITY

This study of PS investigated hospital work systems. Therefore, the application area was the hospital sector. This sector has several characteristics that differ from other sectors (see Section 4.1.1). This influences the generalizability of the core findings and PS taxonomy. Furthermore, the study is based on three case studies, which also limits the generalizability (see Section 5.6.2). However, I have strived to formulate my findings and the PS taxonomy as generically as possible, excluding terms or conditions from the hospital sector. Furthermore, the evaluation workshop of the PS taxonomy and supplemental guides showed that practitioners can apply the taxonomy and guides in planning of PS in other sectors. Therefore, I argue that central principles of the findings and the PS taxonomy can with adaptions be transferred to work system design in other sectors. In this way, the findings and the PS taxonomy have the potential of being relevant in a broader frame of work system design.

10.3 SUGGESTIONS FOR FURTHER RESEARCH

Relevant further research in relation to the three core findings and the PS taxonomy are listed in the following paragraphs.

Core finding 1 underlines that simulation media influence the types of ergonomic conditions that can be evaluated. Simulation media have varying attributes; therefore, the finding indicates that one medium cannot support evaluation of all types of ergonomic conditions. Therefore, combination of simulation media in PS events might increase the variation of ergonomic conditions that can be evaluated. An example could be including table-top models to supplement full-scale mock-ups and in this way obtain the benefits of both media. Furthermore, core finding 1 describes two media attributes. However, other attributes might also be relevant in ergonomic evaluations. Therefore, further research could focus on combination of simulation media and identification of other influencing attributes.

Core finding 2 defines how knowledge creation takes place in PS processes. However, it does not indicate how knowledge creation activities should be combined in sequences and overlaps to foster a particular efficient, creative or innovative PS process. An example could be how many repetitions and iterations of activities are necessary for participants to formulate new design specifications. This insight is relevant to facilitating particular time-efficient PS events. Therefore, further research on PS processes in relation to efficiency, creativity and innovation is relevant.

Core finding 3 addresses the transfer of ergonomic knowledge and the first step of integration in the work system design. Due to time limitations, I did not investigate the integration of the knowledge throughout the whole design process, and I did not have the chance to evaluate the final constructed buildings. This more longitudinal focus is, however, also relevant for understanding knowledge transfer and integration. Further research will either require retrospective studies of the design process of existing buildings and work systems or longitudinal studies following a design process from the beginning to end.

The PS taxonomy and supplemental guides were evaluated by practitioners through a workshop. The evaluation was based on the practitioners' own experiences and projects. Therefore, further research could test the taxonomy and the guides in the context of a real-world work system design project. This would be relevant for further development of the taxonomy.

11. CONCLUSION

In this section, the three research questions of the PhD study are answered individually. The section ends with an overall conclusion.

Participatory simulation (PS) is a method to benefit from employees' knowledge in work system design. In PS, employees are involved in simulation and design of their own future work systems. Only a few studies have investigated PS, and little attention has been devoted to the elements of the method. Yet knowledge of these elements is essential when analyzing and planning PS events in work system design. Therefore, extension of the knowledge base on PS in work system design is important for both research and practice.

As part of a comprehensive renewal process of public Danish hospitals, health care employees are invited to participate in PS events to contribute with their professional knowledge to the design of the new hospitals—their own future hospital work systems. These practical experiences with PS in the Danish hospital sector provided a unique opportunity for investigating the PS method and extending the knowledge base. The study was guided by three research questions that supported development of a PS taxonomy to support 1) researchers in analyzing and categorizing PS and 2) practitioners in planning and facilitating PS.

RQ1: How are simulation media in participatory simulation influencing ergonomic evaluation in design of hospital work systems?

Answer: Simulation media attributes in the form of fidelity and affordance influence the type of ergonomic conditions that can be evaluated in participatory simulation.

This study showed that simulation media have varying attributes and are therefore able to support evaluation of different ergonomic conditions of the future work system. For instance full-scale mock-ups' high fidelity of room layout and affordance of tool operation support ergonomic evaluation related to physical workspace and tools. Small-scale table-top models' high fidelity of relation between functions and affordance of overview support ergonomic evaluation related to work organization. One medium seldom has high fidelity and affordance related to all work system areas; in this way, one medium cannot support evaluation of all types of ergonomic conditions. Therefore, this study conclude that the media attributes' influence on the types of ergonomic conditions that can be evaluated is important to consider when selecting simulation medium in planning of PS.

RQ2: How is ergonomic knowledge created in participatory simulation in design of hospital work systems?

Answer: Sequences and overlaps of knowledge creation activities are the sources of ergonomic knowledge creation in participatory simulation.

This study introduced knowledge creation theory to PS and thereby provided a new perspective on the PS method. This resulted in PS being viewed as a process of simulation participants creating ergonomic knowledge in the form of design specifications to be communicated to work system designers. The knowledge was created through participants engaging in knowledge creating activities: *sharing work experiences*, *experimenting*, *interacting with the simulation medium*, *reflecting* and *proposing new design*. These activities were connected in sequences and overlaps that resulted in a process in which participants externalized, combined and created new ergonomic knowledge. The sequences and overlaps showed the activities that were essential in the creation of ergonomic knowledge in PS. Therefore, this study concludes that the knowledge creation process is important to take into account when planning and facilitating PS to guide the participants to engage in activities that result in creation of ergonomic knowledge.

RQ3: How is ergonomic knowledge from participatory simulation transferred to hospital work system design processes and integrated into design?

Answer: Intermediary actors and objects embedding ergonomic knowledge are means of transfer. Interpretation and transformation of the transferred knowledge are means of integration.

This study applied knowledge transfer and integration theory to PS and therefore found intermediaries have a knowledge transferring ability. In this way, the focus shifted from the execution of PS to the subsequent handling of the created ergonomic knowledge. Objects documenting the PS outcome and design actors participating in PS have intermediary abilities and therefore were means for transferring the created knowledge to the work system design process. The integration of the transferred ergonomic knowledge was not greatly affected by the form of the knowledge, e.g., tangible design specifications or more intangible recommendations. Instead, design constraints resulted in designers interpreting and transforming the received knowledge as means for integration. The knowledge transfer and integration showed to be central for PS to get an impact on the work system design. Therefore, this study concludes that planning of knowledge transfer and integration is just as important as planning of the PS event itself.

The answers to the three research questions show that PS is a relevant method in work system design to benefit from employees' knowledge in ergonomic evaluation and ergonomic knowledge creation, transfer, and integration. However, the answers to the research questions also show that the PS method comprises several elements that influence and promote ergonomic evaluation and ergonomic knowledge creation, transfer, and implementation. Therefore, PS is not a "one size fits all" method. Instead PS has to be planed and facilitated in accordance with the specific situation and intended outcome.

The PS taxonomy developed in this study gives an overview of the PS elements and thus contributes to the limited knowledge base on PS in work system design in the ergonomics field. The taxonomy provides a frame for categorizing and analyzing PS from a research perspective as well as planning and facilitating PS from a practice perspective. Furthermore, the PS taxonomy brought the results of this study from the Danish hospital sector toward a more generic level. Evaluation of the taxonomy by practitioners showed that elements are transferable and adaptable to work system design in other contexts and sectors than the hospital sector.

As the overall conclusion, I argue that PS is a highly potential method for ergonomic work system design, but the different PS elements have to be carefully and deliberately planned and facilitated to harness this potential and achieve an actual design impact.

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APPENDIX A: REVIEW OF MEDIA CAPABILITIES

Type of medium	**Medium capabilities**
Abstract models, e.g., Post-it based overviews or brick games	- Enables simulation of organization and division of resources (Daniellou et al. 2014) - Enables representation of knowledge on the overall organization of areas (Conceição et al. 2012) - Provides overview of the existing and new work organization (Ruohomäki 2003; Våland & Georg 2014)
Layout plan	- Provides overview of the overall evolution and design (Villeneuve et al. 2007; Bligård et al. 2014; Persson et al. 2014) - Provides limited interaction among participants (Bligård et al. 2014) - Difficult for participating workers/non-experts to interpret and understand (Persson et al. 2014; Koningsveld et al. 2005)
Small scale 3D models, e.g., a small scale model of a complete building	- Provides rearrangement of equipment and a hands-on experience (Bligård et al. 2014) - Provides overview of division of labor (Broberg & Edwards 2012) - Provides a understanding of spatial dimensions (Seim & Broberg 2010) - Forces participating workers' verbalizing procedures (Seim & Broberg 2010)
Full-scale mock-ups, e.g., a 1:1 wood model of a room	- Relevant in evaluation of concepts (Wilson et al. 2005) - Relevant in early design in combination with scenarios (Béguin 2011) - Valuable when the room is intended to be extensively reproduced in a building (Villeneuve et al. 2007) - Have to be flexible in use to test several room layouts (Villeneuve et al. 2007) - Workers experience the real dimensions of the rooms in relation to their own bodies and therefore are immersed in the proposed design (Villeneuve et al. 2007; Bligård et al. 2014; Persson et al. 2014; Davies 2004) - Testing of room layout and work practices within the room (Hignett et al. 2010; Paquet & Lin 2003; Watkins et al. 2008) - Testing of the interior positioning in the room (Steinfeld 2004; Peavey et al. 2012; Persson et al. 2014) - Testing material choices (Peavey et al. 2012)
Prototypes, e.g., detailed models of work stations	- Relevant for solution generation (Wilson et al. 2005) - Relevant in detailed design in which the knowledge is sufficient to build a prototype (Béguin 2011) - Workers testing functional attributes of the design therefore get personal experience (McClelland & Suri 2005; Barcellini et al. 2014) - Anticipating functioning of technology (Norros 2014) - Testing work postures (Fritzsche 2010)

3D drawings, e.g., CAD-based drawings.	- Enables visualization of reference points in the future buildings (Villeneuve et al. 2007) - Enhances understanding among participants (Sundin & Medbo 2003) - Harder to navigate without experience manipulating CAD systems (Bligård et al. 2014) - Enables identification of specific dimension problems (Persson et al. 2014). - Tests positioning of furniture (Zamberlan et al. 2012)
Computer based models, e.g., math based discrete event simulation	- Enables simulation of interaction between multiple machines, human operators, work practices and rooms at the same time (Paquet & Lin 2003; Persson et al. 2014)
Virtual reality, e.g., workers are wearing virtual reality glasses	- Relevant for concept evaluation (Wilson et al. 2005) - Stimulates discussions about specific topics (Persson et al. 2014) - Visualizes an entire building (Persson et al. 2014) - Hard to reproduce tasks in the virtual environment (Persson et al. 2014) - Provides the possibility for walk-throughs (Wilson 1999). - Visualizes color and light (Davies 2004)
Mixed reality, e.g., combination of computer-based models and mock-ups	- Tests work postures at new work station layout (Hallbeck et al. 2010; Hu et al. 2011; Koningsveld et al. 2005) - Identifies future usage functions of work equipment and associated safety issues (Marc et al. 2007) - Visualizes ergonomic problems for the workers (Koningsveld et al. 2005)

APPENDIX B: REVIEW OF WORK SYSTEM MODELS

Work system models	System entities	Definition of work system
Sociotechnical system approach of macroergno-mics (Kleiner 2006)	Technical subsystem Personnel subsystem Environment Organizational design	"A work system comprises two or more people working together (i.e., personnel subsystem), interacting with technology (i.e., technological subsystem) within an organizational system that is character-ized by an internal environment (both physical and cultural)." (Kleiner 2006)
SOFT, the four dimensions of workplaces (Horgen et al. 1999)	Space Organization Finance Technology Work Practice	"The workplace as a strategic element of the organization…depends upon the internal compatibility - indeed, the ac-tive mutual reinforcement - of spatial, organizational, financial and technologi-cal arrangement. " (Horgen et al. 1999)
The work system model/SEIPS model (Carayon 2009)	Individual Tools and Technologies Task Environment Organization	"According to the work system model, tasks are performed by an individual who uses tools and technologies; the tasks are performed in a physical envi-ronment and under organizational condi-tions. " (Carayon 2009)
The work system framework (Alter 2006)	Participants Information Technologies Processes and activities Products and services Customers Environment Infrastructure Strategies	"A work system is a system in which human participants and/or machines perform work using information, tech-nology, and other resources to produce products and/or services for internal or external customers….The elements of work practice, participants, information and technologies are the components that actually are performing the work. " (Alter 2006)
Socio-technical framework (Davis et al. 2014)	Goals People Buildings/infrastructure Technology Culture Processes/procedures Financial/economic circumstances Regulatory frameworks Stakeholders	"…a work system will usually have a set of goals and metrics, involve people (with varying attitudes and skills), using a range of technologies and tools, work-ing within a physical infrastructure, op-erating with a set of cultural assump-tions, and using sets of processes and working practices. The system sits with-in a wider context, incorporating a regu-latory framework, sets of stakeholders (including customers), and an econom-

		ic/financial environment." (Davis et al. 2014)
SHELL model (Renouard & Charrier 2012)	Software: producers, training, support Hardware: Technical systems and equipment Environment: Physical, social and operational context Lifeware: Front-line actors	"… interactions between and individual and their work environment, comprising other people (liveware), technology (hardware), documentation (software) and the surrounding environment (environment)." (Renouard & Charrier 2012)

Appendix C: Observation guide

Observation guide	
Personal focus	My personal focus and expectations of the PS event
Introduction	The aim and the purpose described by the facilitators and simulation participants
Before the simulation	Preparation: The activities taking place just before the actual simulation The actors involved in the preparation activities The artefacts applied in the preparation activities
During the simulation	Participants: The simulation participants The reason for their participation The role of the different participants The contribution of the different participants
	Procedure: The location of the simulation The main discussions during the simulation The main decisions during the simulation The facilitation of the simulation
	Type of simulation and simulation media: Experimental simulation or narrative simulation Application of scenarios Application of and interaction with simulation media Modification and changes done to the simulation media
	Ergonomics: The ergonomic challenges articulated When the ergonomic challenges were articulated
	Results and documentation: The final agreements and results of the simulation The documentation of these results
After the simulation	The parsing on: The plan for the subsequent communication of the documented results
Other in-sights	Other insights not covered by the above categories, but still interesting in relation to the overall understanding of the PS event

APPENDIX D: INTERVIEW GUIDES

Interview guide for PS participants	
Introduction	I present the purpose of my PhD project and the specific purpose of the interview. This includes what I expect the interview will be applied for.
Background of the interviewee	Can you give me a short introduction to your position, professional background and position in the organization?
Before the simulation	Why did you participate in the PS events? Have you participated before? What was your expectation of the PS event? How did you prepare for participating?
During the simulation	How did the PS events live up to your expectations? What was you focus during the PS event? Do you think you went through all the relevant scenarios in the PS events? Which could have been elaborated?
	Simulation media: What did it mean for you that the simulation applied a table-top model/full-scale mock-up/blueprint? What are the advantages and challenges of table-top model/full-scale mock-up/blueprint?
	The location: What did it mean for you that the PS took place in the facilities of …/in the design lab of…/in the meeting room of…?
	Participants: What role did you feel you took during the PS event? What do you think about the roles of the other participants? Did you miss some types of participants? Which?
	Results: What ergonomic conditions did you become aware of? Did you expect these ergonomic conditions to be revealed?
	Results and documentation: How did you document the results of the PS event? How do you communicate the results to your colleagues?
After the simulation	What happened to the documented results after the PS event?

Interview guide for designers in the work system design process	
Introduction	I present the purpose of my PhD project and the specific purpose of the interview. This includes what I expect the interview will be applied for.
Background of the interviewee	Can you give me a short introduction to your position, professional background and position in the organization?
Received ergonomic knowledge from PS	What kind of ergonomic knowledge do you need in the different design phases? What kind of ergonomic knowledge have you obtained from (the specific PS events of the case study)? How did you get this knowledge?
Application of received ergonomic knowledge	How do you apply the received ergonomic knowledge? What role does the knowledge have in the design process? How do you handle ergonomic considerations in the design process? Who has the responsibility for integration of ergonomic knowledge in the design?
The design organization	Collaboration with project owner: How are you communicating with the project owner and the innovation lab? Who is communicating with the project owner and the innovation lab?
	The organization: Who many designers do participating in the consulting consortium? What are the different consortium participants' responsibilities? Where in the design organization are you positioned? How is the work and the management divided between the different consortium participants? What professional specializations are represented in the design organization?
The buildings process	Which design phase is the xxx project currently in? What are the different consortium participants contributing in the different design phases? Are some participants contributing more than others in specific phases?
The aim of the designers	What is the aim of the design consortium in relation to projects xxx?

Appendix E: Conference paper 1

Simulation in full-scale mock-ups: an ergonomics evaluation method?

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Abstract. This paper presents an exploratory study of four simulation sessions in full-scale mock-ups of future hospital facilities. The aim was to explore full-scale mock-ups' potential of not only being a method for testing and evaluating design concepts but also being an ergonomics evaluation method of specific work conditions at future hospital facilities. The results show that the simulation in the full-scale mock-ups revealed work conditions of Room Layout, Musculoskeletal Conditions, Organizational Interconnections, Indoor Climate, Safety and Psychosocial Conditions. However, the full-scale mock-ups were primarily supporting ergonomics evaluation of Room Layout and Musculoskeletal Conditions.

Keywords. Full-scale Mock-ups, Hospitals, Simulation, Participatory Ergonomics.

1. Introduction

Direct participation of workers in participatory ergonomics design process is considered to be a success factor for increasing comfort and productivity of the workers (Vink, Koningsveld, & Molenbroek, 2006). Within the design process of hospital buildings participatory ergonomics is utilized to increase the performance of healthcare teams and hospital facilities (Villeneuve, Lu, Hignett, & Duffy, 2007). The Danish healthcare sector is currently applying a participatory approach in a comprehensive renewal process of its hospital buildings and facilities. A key method in the renewal process is simulation in full-scale mock-ups, which is facilitated by regional innovation centers and involving healthcare professionals, architects and engineers.

Simulation in full-scale mock-ups is a recognized participatory ergonomics method in design of buildings and facilities. The method is used for testing layout, exploring design challenges and evaluating design concepts (Villeneuve et al., 2007; Watkins, Myers, & Villasante, 2008; Wilson, Haines, & Morris, 2005). This paper aims at exploring how full-scale mock-ups simulation not only is a method for testing and evaluating design concepts but also an ergonomic evaluation method for evaluating specific work conditions in hospital facilities.

The paper presents an exploratory study of four simulation sessions in full-scale mock-ups in the building design process of a major Danish hospital. The immediate purpose of the sessions was to test and evaluate architectural design concepts. An additionally ergonomics evaluation potential was explored through the research questions: 1) What is the potential of simulation in full-scale mock-ups in revealing and evaluating the work conditions of future hospital facilities, and 2) which specific work conditions are revealed and evaluated?

1.1 The four full-scale mock-ups sessions

The four full-scale mock-ups sessions were managed by a major Danish hospital and situated in the local regional innovation center. The innovation center's aim is to test and develop concepts for room size, layout, working procedures and logistics. The purpose being strengthening the planning process of future hospital facilities and thereby improving continuity in patient care and work environment of the healthcare professionals (DNV-Gødstrup, 2012). The mock-up sessions were organized and facilitated by two innovation center employees, one with an ergonomic background and one with a clinical background.

The innovation center has facilities, such as movable walls, simple foam bricks and standard hospital furniture, to construct full-scale mock-ups of hospital rooms and corridors, see figure 1. These facilities have so far allowed mock-up sessions testing the architectural drawings of layout concepts of future hospital rooms. Having a participatory approach the sessions involve healthcare professionals from current regional hospitals, representative from the project owner, consulting architects and engineers in testing the architectural layout concepts.

Figure 1, mock-ups of movable walls, foam bricks and standard hospital furniture.

A typical mock-up session in the innovation center is constituted by two parts, an introductory part and a testing part. In the introductory part, the participants and the facilitators discuss work procedures and possible challenges of proposed room layouts, with foundation in the healthcare professionals' experiences from their own work. In the testing part, the participants enact and discuss scenarios of future work practices, enabling discussions on the room layouts' implications on work practices and identification of possible layout improvements. The healthcare professionals are developing the scenarios continually during the testing with foundation in own experiences and the discussions from the introductory part of the sessions.

The enactment of the scenarios during the testing part of a session relates to experimental simulation (Daniellou, 2007) because the participants are physically testing the scenarios. The discussions of the scenarios relate to narrative simulation (Daniellou, 2007) because the participants articulate feasible ways to carry out future work tasks in the room. Both types of simulations lead to reflections, which often result in mock-ups adjustments, leading to new experimental or narrative simulations. The simulations are supported by the full-scale mock-ups functioning as simulation models (Gupta, 2013). The facilitators' role is making sure that all discussed aspects from the introductory part are covered during the tests. The four sessions constituting the foundation for this paper, are presented in table 1.

Table 1, the four full-scale mock-ups sessions.

	Session 1	**Session 2**	**Session 3**	**Session 4**
Archi-tectural room concepts	Standard reception and back-office for bed wards.	Standard examination room of outpatient department.	Standard depot for bed wards.	Standard bed paternoster lift.
Partici-pants	- Three medica secretaries. - One executiv medical secretary - Two executiv nurses. - Three hospita managers. - Two IT consultants.	- Three medical secretaries. - One executive medical secretary. - Two executive nurses. - Three from the hospital management. - Two IT consultants.	- Three executive nurses. - One from the hospital management. - One from the project division focusing on logistics.	- One hospital porter - One technica employee. - Two from the projec division. - One architect - One project engineer - Two technica consultants.
Facilita-tors	- The facilitator with clinical background. - The facilitator with ergonomic background.	- The facilitator with clinical background. - The facilitator with ergonomic background.	- The facilitator with clinical background.	- The facilitator with clinical background. - The facilitator with ergonomic background.
Purpose	Making the reception appealing to the patients. Test whether large touch screens could fit into the back-office.	Redesigning the layout of the examination room to optimize patient experience and work conditions.	Optimizing the layout of the depot to obtain the necessary storage without compromising the work conditions.	Find the minimum dimensions for the paternoster lift without compromi-sing work conditions of the porter.
Duration	1 hour	1 hour	1,5 hours	2 hours

2. Methods

The data was collected through observations of the introductory parts and observations and video recording of the test parts of the four full-scale mock-ups sessions. The video recordings constituted the primary data foundation. However, the observations of the introductory parts helped understand the rationale behind participants' actions and discussions during the testing parts of the sessions.

We analyzed the video recordings by coding each recording to identify mock-ups adjustments and topics addressed by the participants, both relating to and influencing the future work conditions of the healthcare professionals. The coded mock-ups adjustments and topics were noted on paper. We analyzed the large amount of notes by applying an inductive affinity diagram approach (Beyer & Holtzblatt, 1998). The observations of the introductory parts of the mock-ups sessions helped in understanding the underlying meanings of the notes. In the development of the affinity diagram, the data formed 14 topics and 6 overlaying categories. Each topic was quantified by counting the number of notes per topic in relation to each of the four sessions. The quantification showed the distribution of the different topics between the four mock-ups sessions.

3. Results

Table 2 presents the results of the analysis of the four mock-ups sessions. The first column presents two types of categories, firstly, factors influencing work conditions (referred to as influencing factors in the following sections), secondly, direct work conditions. The columns three to six present the number of times each topic was revealed during each session. Column seven presents the number in total in relation to each topic.

Furthermore, column eight presents the number of mock-ups adjustments in relation to each overlaying category.

Table 2, analysis results of the four full-scale mock-ups sessions.

Overlaying categories	Topics	Session 1	Session 2	Session 3	Session 4	Total	Mock-ups adjust-ments
Room Layout	Room size and dimensions	2	0	3	16	21	11
	Type of furniture in the room	1	11	12	4	28	
	Dimensions and space needed for furniture	8	4	25	14	51	
	Layout of furniture in the room	1	5	11	0	17	
	Working procedures in rooms in relation to layout of furniture	0	2	4	12	18	
Musculo-skeletal Conditions	Design of permanent workstations	8	1	0	0	9	6
	Work posture in relation to rooms and furniture	0	0	13	14	27	
Organi-zational Intercon-nections	The rooms' connec-tions to other rooms	2	3	0	3	8	0
	Logistics in relation to the rooms	0	2	2	5	9	
Indoor Climate	Noise in relation to workspaces	1	0	0	4	5	1
	Draught in workspaces	1	0	0	0	1	
	Inflow of light from windows to workstations	3	1	3	0	4	
Safety	Safety of the work space	0	0	1	8	9	0
Psychosocial Conditions	Rooms' influence on employees' psycho-social conditions	6	0	0	0	6	0

4. Discussion and Conclusion

The full-scale mock-ups sessions revealed following categories of work conditions, Musculoskeletal Conditions, Indoor Climate, Safety and Psychosocial Conditions. Additionally, the sessions revealed following categories of influencing factors, Room Layout and Organizational Interconnections. However, not all categories led to mock-up adjustments and ergonomics evaluations by the participants. The full-scale mock-ups primarily supported evaluation of Room Layout and Musculoskeletal Conditions.

4.1 *Revealed work conditions*

The most frequently addressed categories, Room Layout and Musculoskeletal Conditions, were revealed during the experimental and narrative simulations. The high frequency indicates the mock-ups ability to enable the participants envision, how future room layouts would influence work practices and work postures, in a simply and straight forward manner. This ability was shown during the participants' enactments, which instantly directed the participants' discussions towards the physical work conditions of future hospital facilities. Even though the facilitators varied in the third session, the four sessions showed all the same tendency of frequent addressed Room Layout and Musculoskeletal Conditions. This tendency indicates that the high focus on the physical work conditions was in some degree independent from the background of the facilitators.

The categories, Organizational Connections, Indoor Climate, Safety and Psychosocial Conditions, were mainly revealed during the narrative simulations. The category of Organizational Connections stands out because it includes the tested rooms' connection to other rooms and functions, while the categories Indoor Climate, Safety and Psychosocial Conditions focus on the tested rooms independently from external functions. The revealing of these four categories showed to be influenced by the participants' professional background in the form of their current workplaces and work practices. The participants' professional background was the starting point for many of the narrative simulations. This was especially the case in the category of Psychosocial Conditions, where the current work pressure of the participants encouraged discussions on how future room layouts could affect the work pressure. The four sessions were to a great extend driven by the participants and influenced by their respectively professional backgrounds, while the facilitators had a more supporting role.

4.2 Ergonomics evaluation potential

The results show that the simulation in the mock-ups revealed categories of different work conditions and influencing factors. However, the participants were not able to evaluate all the revealed conditions because the mock-ups showed to be more supportive in evaluating some work conditions than others.

The mock-ups' ability to show the room layouts' impacts on work practice and work posture highly supported the revealing of the categories Room Layout and Musculoskeletal Conditions. The participants' discussions of the impacts had ergonomics evaluation characteristics since participant conversations included assessments of the identified impacts. The evaluations led to 'local problem solving' in the form of mock-up adjustments, which resulted in redesigns of the architectural proposals on the spot. The categories Room Layout and Musculoskeletal Conditions had a high degree of mock-ups adjustments, indicating an ergonomics evaluation potential of the mock-ups in relation to these two categories.

The categories Organizational Connections, Indoor Climate, Safety and Psychosocial Conditions were not in the same degree supported by the full-scale mock-ups as the categories of Room Layout and Musculoskeletal Conditions. In the revealing of the Organizational Connections, the participants identified problems in the connections between the tested rooms and other rooms of the future hospital. However, it was difficult for the participants to evaluate these problems because the mock-ups solely represented few rooms or corridors and not the external rooms or functions. Thereby, the mock-ups supported intensive focus on specific rooms or corridors having a tendency to isolate rooms and only showing the work practices taking place within these specific rooms. The ergonomics evaluation potential of Organizational Connections was thereby weaker than the evaluation potential of Room Layout and Musculoskeletal Conditions.

The mock-ups as simulation models were abstractions of complex future realities (Gupta, 2013) and were thereby only reflecting the future reality to a certain degree. The difference between a future reality and the present mock-ups prevented participants in making accurate evaluations of the category Indoor Climate because work conditions such as natural inflow of light and acoustics were not reflected by the full-scale mock-ups. The mock-ups were situated in a workshop at the innovation center, which did not allow the natural inflow of light in the mock-ups. Furthermore, the mock-ups were built with primitive materials, which did not reflect the acoustic abilities of the intended materials. Nevertheless, the mock-ups sessions resulted in an evaluation leading to one mock-up adjustment. The adjustment was in relation to the position of fixed furniture to hypothetically obtain as much natural light inflow as possible in the room. The abstraction level of the mock-ups showed thereby evaluation potential of Indoor Climate work conditions to a limited extend.

To sum up, the full-scale mock-ups supported ergonomics evaluations of Room Layout and Musculoskeletal Conditions. The categories of Organizational Connections, Indoor Climate, Safety and Psychosocial Conditions were revealed by the mock-ups but the evaluation potential was weaker.

4.3 Improving ergonomics evaluation potential

The study of the four mock-up sessions indicated that the facilitation of the sessions were open, thereby these sessions ended up being primarily defined by the participants and their professional backgrounds. The participants were not actively focusing the sessions towards ergonomics evaluations, instead their focus was on testing the physical layout of the rooms. The analysis of the sessions indicated a latent potential for improving the ergonomics evaluation abilities of the mock-ups in relation to the categories Room Layout and Musculoskeletal Conditions. Therefore, we suggest to strengthen the facilitators role towards initiating and guiding the sessions (Haines, Wilson, Vink, & Koningsveld, 2002), thereby increasing the facilitators ability to control the direction of the sessions. The facilitators could accomplish this by asking questions directly related to the work conditions under evaluation, although it is important to note that the process should still remain participant driven through their inputs and initiatives.

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APPENDIX F: JOURNAL PAPER 1

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Participatory ergonomics simulation of hospital work systems: The influence of simulation media on simulation outcome

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Participatory ergonomics

ABSTRACT

Current application of work system simulation in participatory ergonomics (PE) design includes a variety of different simulation media. However, the actual influence of the media attributes on the simulation outcome has received less attention. This study investigates two simulation media: full-scale mock-ups and table-top models. The aim is to compare, how the media attributes of *fidelity* and *affordance* influence the ergonomics identification and evaluation in PE design of hospital work systems. The results illustrate, how the full-scale mock-ups' high fidelity of room layout and affordance of tool operation support ergonomics identification and evaluation related to the work system entities *space* and *technologies & tools*. The table-top models' high fidelity of function relations and affordance of a helicopter view support ergonomics identification and evaluation related to the entity *organization*. Furthermore, the study addresses the form of the identified and evaluated conditions, being either identified challenges or tangible design criteria.

1. Introduction

A recognized problem in work system design is the occurrence of ergonomics problems after implementation of system changes, resulting in resource demanding and costly readjustments to comply with the problems (Hendrick, 2008). One way of preventing the ergonomics problems already during the design process is to include the future workers in participatory ergonomics (PE) (Wilson et al., 2005). PE has been defined as "the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals" (Wilson, 1995).

Participatory simulation is a PE method that involves the future workers in design of work systems. A work system can be defined as "… a system in which human participants and/or machines perform work using information, technology, and other resources to produce products and/or services for internal or external customers" (Alter, 2006). Simulation has been defined as "an imitation of the operation of a real-world process or system over time" (Banks et al., 2010), and may have two purposes. The first being a method for identifying and evaluating the future work practices and ergonomics conditions (Daniellou, 2007; Daniellou et al., 2014; Nelson et al., 2013) and the second being a social process mediating mutual learning between workers and designers (Béguin, 2014). This study will concentrate on the first purpose.

A key component in participatory simulation is the simulation media (Daniellou, 2007), which represent the work system to be designed. Within the PE field, a variety of different simulation media are applied, all with the purpose of identifying or assessing ergonomics conditions and problems of the work system to be designed. Physical simulation media such as mock-ups and prototypes are applied for assessing work posture (Sundin et al., 2004), muscular discomfort (Paquet and Lin, 2003), physical layout and spatial conditions (Broberg et al., 2011; Steinfeld, 2004; Watkins et al., 2008). Computer based simulation media such as 3D computer animation and mixed reality have been applied for assessing muscular fatigue (Hallbeck et al., 2010; Perez et al., 2014), repetitive work and critical work sequences (Sundin and Medbo, 2003; Sundin et al., 2004).

The variation in ergonomics conditions indicates that different media support identification and assessment of different ergonomics conditions, which is a common reflection point in the literature (Hallbeck et al., 2010; Paquet and Lin, 2003; Steinfeld, 2004; Sundin and Medbo, 2003; Watkins et al., 2008). In addition, some studies indicate that the media have certain attributes,

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but these are not reflected upon in relation to the ergonomics conditions or problems actually possible to identify by applying the media. The media attributes indicated are the ability of the media to represent the reality (Hallbeck et al., 2010; Steinfeld, 2004; Watkins et al., 2008) and the possible actions the media support (Broberg et al., 2011; Steinfeld, 2004). Within the interaction design field, these attributes are recognized as *fidelity* (Hall, 2001; Lim et al., 2008) and *affordance* (Norman, 2002; Turner, 2005). Fidelity may be defined as “the level of detail or sophistication of what is manifested” (Lim et al., 2008). Affordance may be defined as “the perceived and actual properties of the thing… that determine just how the thing could possibly be used” (Norman, 2002). How these two media attributes influence the outcome of simulations, in the form of identified ergonomics conditions, has received little attention in the participatory simulation field.

The Danish healthcare sector is currently a relevant empirical setting for exploring the influence of the simulation media attributes. At the moment, the sector is in a comprehensive design process of new public hospitals, which includes an extensive application of participatory simulation, involving healthcare professionals in PE design. The design activities may be conceptualized as a matter of designing hospital work systems. This study is based on two case studies of participatory simulation events, applying two different simulation media: full-scale mock-ups and table-top models. The aim is to compare, how the fidelity and affordance attributes of these two types of simulation media may influence the ability to identify and evaluate ergonomics conditions during PE design of hospital work systems.

Our basic assumption was that the two simulation media would have different capabilities in supporting *identification and evaluation of ergonomics conditions* because of difference in the attributes. By adapting the International Ergonomics Association's definition, *ergonomics conditions* are defined as: (1) conditions influencing the healthcare professionals' well-being in the future work system, e.g. work posture, psychosocial work load, indoor climate, safety and division of labor; and (2) conditions influencing the work system's overall performance, e.g. efficiency, consumption of resources, quality of system output and risk of errors. We refer to *identification* as the process of simulation participants being able to articulate or visually show possible ergonomics challenges of the future work system. We refer to *evaluation* as the process of participants being able to formulate tangible design criteria based on discussions of the identified ergonomics conditions.

In the following, we first define the key work system concept, followed by the methodological approach, including the introduction of the two cases. We present the results from the analysis in the form of the identified and evaluated ergonomics conditions of the two cases and the influence of fidelity and affordance. In the discussion, the results of each case are compared and related to existing studies on full-scale mock-ups and table-top based models. We end with concluding remarks, including implications for practitioners.

2. The work system concept

In order to analyze the participatory simulation phenomenon, we introduce the work system concept. A work system has been defined as consisting of different interconnected entities (Alter, 2006; Carayon, 2009; Horgen et al., 1999; Kleiner, 2006). We operate with six entities: *work practice*, *participants*, *information*, *technologies & tools*, *space* and *organization*. The *work practice* is the work activities within the work system (Alter, 2006). The *participants* are the people who perform the work (Alter, 2006) and have psychosocial, cognitive and physical characteristics (Carayon, 2009). The *information* is explicit and tacit knowledge, which is exchanged as participants perform their work (Alter, 2006). The *technologies & tools* are the tools that help participants work efficiently (Alter, 2006; Carayon, 2009). The *space* is the physical environment and workspace design (Carayon, 2009; Horgen et al., 1999). The *organization* is the organizational design, the organization of work, coordination of work (Kleiner, 2006), work scheduling and culture (Carayon, 2009). The six entities of the work system concept are applied as an analytical frame to help identify, to what extent the entities are addressed in the two simulation cases.

3. Methodology

The Danish healthcare sector is designing and building new public hospitals, with the purpose of increasing the quality and efficiency of the healthcare service. The design process includes redesign of the current hospital work systems. To facilitate user participation in the work systems design, the Danish Regional Councils have established innovation centers spread around the country. A significant part of the centers' activities is based on participatory simulation, involving healthcare professionals from the existing hospitals. We had the opportunity to study participatory simulation in two innovation centers, each related to a hospital design project. The first center applied full-scale mock-ups as simulation media, and the second center applied table-top models as simulation media. We considered the simulation activities of the centers as naturally occurring data, described as “real interactions happening naturally out in the world” (Potter, 2004), contrasting controlled laboratory experiments. These naturally occurring simulation activities provided a unique opportunity for studying, how the fidelity and affordance of these two types of simulation media may influence the ability to identify and evaluate ergonomics conditions. We approached the simulation activities of the two hospital design projects as two case studies, each constituting of four simulation events viewed as nested units of analysis (Thomas, 2011). The simulation activities in both cases had the purpose of providing input to the engineers and architects, who designed the new hospital buildings during complex design processes. However, in this study we focus exclusively on the actual ergonomics outcomes of the simulations. The two cases are described in the following Sections 3.1 and 3.2.

3.1. Full-scale mock-ups

The innovation center of the first case study was part of the building process of a new hospital, which replaced two current hospitals. The center was located in a hall at the construction site, containing mock-ups facilities. The facilities were managed by two center employees: one with a clinical background and one with an occupational health and safety background. The purpose of the center was to test standard room proposals for the somatic hospital and thereby contribute to the architectural design process.

The four simulation events, constituting the case as presented in Table 1, were based on blueprints of room proposals provided by the consulting architects. The room proposals were key rooms in the sense that the rooms would be extensively repeated throughout the hospital. The proposals were transformed into full-scale mock-ups based on movable chipboard walls, big foam bricks and standard hospital interior, see Fig. 1. The mock-ups were constructed by the two center employees prior to the simulation events.

The participants of the four simulation events were healthcare professionals with various professions; project employees from the project owner organization; engineers and architects from the consulting companies; and the two center employees. The center employees selected the participating healthcare professionals on the criteria of having work experience in the room to be tested.

Table 1
Key characteristics of the four simulation events of the first case study.

	Sim event 1	Sim event 2	Sim event 3	Sim event 4
Duration	1 h	1 h	1.5 h	2 h
Simulation medium	Full-scale mock-up of standard reception in bed ward.	Full-scale mock-up of standard examination room in outpatient department.	Full-scale mock-up of depot in standard bed ward.	Full-scale mock-up of standard bed paternoster lift and hallway.
Participants	- Three medical secretaries. - One executive medical secretary. - Three executive nurses from three areas of specialization. - One staff member from hospital management group. - One staff member from project division focusing on space documentation. - Two IT consultants. - Two center facilitators.	- Three medical secretaries. - One executive medical secretary. - Three executive nurses from three areas of specialization. - One staff member from hospital management group. - One staff member from project division focusing on space documentation. - Two IT consultants. - Two center facilitators.	- Three executive nurses from three areas of specialization. - One staff member from project division focusing on logistics. - One staff member from project division focusing on space documentation. - Two center facilitators.	- One hospital orderly. - One employee from the hospital technical department. - Two staff members from project division focusing on logistics. - One consulting architect. - One project engineer. - Two technical consultants. - Two center facilitators.
Purpose	Exploring work tasks of logistical coordination within the layout of the reception and back office area.	Exploring work tasks of patient examination within the layout of the examination room.	Exploring work tasks of aids handling and storage within the layout of the depot.	Exploring work tasks of bed handling within the layout of the bed paternoster and hallways.

Fig. 1. Full-scale mock-ups applied in the first case.

Each of the four simulation events constituted of two parts. The first part was an introduction meeting, where the center employees introduced the simulation participants to the architect's room proposal. The introduction led to discussions of possible challenges of the room, e.g. problems about work postures or work practices. Using the identified challenges as a starting point, the participants developed scenarios based on possible future work practices, e.g. handling of a wheelchair in an examination room. The second part comprised the simulation in which the healthcare professionals initiated work processes in the mock-ups. The simulation was facilitated by the center employees in an open manner, in the sense that the direction of the simulation was highly influenced by the participants continually developing the simulation scenarios further. The continual scenario development resulted in a mixture of; experimental simulation, where the participants enacted scenarios in the mock-ups, e.g. pushed a bed around a corner; and narrative simulation, where the participants discussed scenarios while standing in the mock-ups, e.g. how coordinating technology could support the work of the nurses.

3.2. Table-top models

The simulation events of the second case study were a part of a healthcare innovation project managed by the regional innovation center. The project aimed at contributing to the design of a new outpatient department building for an existing hospital. Furthermore, the project was a research project for testing simulation methods in healthcare innovation. The vision for the project was to involve healthcare professionals from the existing outpatient department, consultants from industry, simulation consultants from the Danish Institute of Medical Simulation and researchers.

The four simulation events of the case are presented in Table 2. The simulation media were in table-top size, consisting of an A0-poster, where LEGO figures and cardboard boxes were arranged, see Fig. 2. The LEGO figures depicted patients and healthcare professionals. The cardboard boxes illustrated rooms, and the configuration of the boxes illustrated conceptual building layouts. With a foundation of comprehensive research in the work practices of the current outpatient department, the layout proposals were developed by the participating healthcare professionals before each simulation event.

The participants of the four simulation events were healthcare professionals from the existing outpatient department, simulation consultants, consultants from industry and researchers. However, the healthcare professionals had the most active simulation role, whereas the researchers and consultants from industry observed and occasionally participated, when multiple patient treatments were simulated. Furthermore, one of the simulation consultants acted as the main gamemaster. The participating healthcare professionals were selected by the management of the outpatient department based on the criteria of including representatives from the three main employee groups: physicians, nurses and secretaries.

Table 2
Key characteristics of the four simulation events of the second case study.

	Sim event 1	Sim event 2	Sim event 3	Sim event 4
Duration	1.5 h	1.5 h	2 h	1.5 h
Simulation medium	Table-top model of separate examination and conversation rooms.	Table-top model of one examination room per two conversation rooms.	Table-top model of multifunctional examination rooms and staff area.	Table-top model of multifunctional examination rooms and staff area.
Participants	- One chief surgeon related to the outpatient department. - One outpatient department nurse. - One medical secretary. - One OHS consultant from industry. - Two simulation consultants. - Three researchers in performance and ergonomics.	- One chief surgeon related to the outpatient department. - One outpatient department nurse. - One medical secretary. - One OHS consultant from industry. - Two simulation consultants. - Three researchers in performance and ergonomics.	- One chief surgeon related to the outpatient department. - One outpatient department nurse. - One medical secretary. - One OHS consultant from industry. - Two simulation consultants. - Three researchers in performance and ergonomics.	- One chief surgeon related to the outpatient department. - Three outpatient department nurses. - Two outpatient department physicians. - One OHS consultant from industry. - One construction consultant from industry. - One simulation consultants. - Three researchers in performance and ergonomics.
Purpose	Exploring work tasks of patient examination within the classic layout of the outpatient department.	Exploring work tasks of patient examination within layout based on a shared examination room per two conversation rooms.	Exploring work tasks of patient examination within layout based on multifunctional examination rooms.	Exploring work tasks of patient examination within layout based on multifunctional examination rooms.

Fig. 2. Table-top models applied in the second case.

Each of the four simulation events constituted of two parts. The first part was the actual simulation event based on simulation scenarios, previous developed by the simulation consultants and department management. The scenarios were based on comprehensive research of the work practices at the department and illustrated patient trajectories from the existing outpatient department. The scenarios included a list of tasks with assigned simulation time as a third of real time. In combination with the predefined scenarios, each simulation event was aiming at investigating a simulation question, e.g. "what if we introduced two physicians for three examination rooms?"

For the simulation, each of the participants were assigned a scenario role reflecting their professional background, a LEGO figure and a colored marker pen. The participants, who were assigned the role as patients, were supplied with an egg-timer for managing the simulation time of the scenarios. The participants moved the LEGO figures around the table-top model according to the scenario while simultaneously drawing the movements on the A0-poster. During the simulation, the gamemaster introduced predefined disturbances, e.g. the need for experienced physicians supervising less experienced physicians. The disturbances challenged the participants to develop creative solutions within the frame of the scenarios. The second part of the simulation event was an extensive debriefing managed by the gamemaster and the researchers. In the debriefing, the participants were able to discuss the insights obtained from the previous simulation.

3.3. Case selection

Our initial assumption for this study was that different simulation media have different capabilities in supporting identification and evaluation of ergonomics conditions due to variation in media attributes. The two cases provided a unique opportunity for studying this assumption, which until now has received minimal attention in the human factors and ergonomics field. Furthermore, the two cases complied with the case selection criterion on maximum variation (Flyvbjerg, 2006) by applying two 'opposite' simulation media in terms of fidelity and affordance. The variation in fidelity and affordance is elaborated in Table 3. The purpose was to search for both differences and commonalities. Differences in relation to our assumption of different capabilities of the media. Commonalities in relation to a common pattern in how media attributes connect to these capabilities. Identification of commonalities is argued to be strengthened when the cases vary in maximum degree (Neergaard, 2010).

3.4. Data collection and analysis

The data analysis was based on video-recordings of the simulation events. The video-recordings were executed with a fixed

Table 3
The fidelity and affordance of the two simulation media.

Media	Fidelity		Affordance	
	High	Low	High	Low
Full-scale mock-ups	Room layout and specific dimensions of rooms. Positions and dimensions of technologies and interior.	Sole manifestation of single rooms excluding representation of external functions and coordination.	Easy configuration of the movable walls by the participants. Thereby, supporting redesign of the room dimension and shape in full-scale.	No configuration of more than a few rooms, resulting in low possibility for testing collaboration and coordination between several rooms.
Table-top models	Detailed manifestation of the overall building layout, internal relations and coordination.	Blackboxing each of the rooms of the future work system into cardboard boxes, not manifesting layout and the technologies within.	Easy room configuration, giving a helicopter view of the overall building layout. Thereby, providing overview of collaboration and communication between different professions.	No changing of room dimensions and shape, the cardboard boxes had only one geometry, representing the future rooms.

camera with the purpose of getting a wide view of the simulation activities, and thereby capture as much interaction and visual conduct of the participants as possible (Heath et al., 2010). The authors had different roles in relation to the data collection and analysis. The first author recorded and observed the simulation events of the first case. The second author recorded and participated as one of the researchers in the second case, applying an action research perspective. In both cases, the simulation events were not conducted with a research purpose of media attributes in mind, the overall purpose was to contribute to hospital work system design. Thereby, the comparative potential of the cases was recognized afterwards. Aiming at conducting a comparative analysis, the first author analyzed the video-recordings of both cases from the perspective of being an observer of the recorded events. During the analysis the second author acted as discussion partner.

The first author's observations of the 'live' simulations of the first case and the second author's participation in the simulations of the second case provided insights into the activities taking place before and after recording periods. These insights were important for understanding reasons behind discussions and actions of the simulation participants as captured in the recordings. Furthermore, the observations of the first case gave the opportunity for viewing actions, which were not explicit to the camera because e.g. people occasionally stood behind walls in the full-scale mock-ups. In these cases, the observations were necessary to fill in these particular sequences in the video-recording.

The video-recordings of each case were analyzed in two phases. The first phase investigated the types of ergonomics conditions identified in both cases from a quantitative perspective. The second phase investigated the evaluation possibility of the identified conditions and the relation to the media attributes from a qualitative perspective. The two phases of analysis were intended to supplement each other by providing both a quantitative and qualitative view on the two case studies as a triangulation strategy (Silverman, 1993). The two phases are illustrated in Fig. 3 and elaborated in the following paragraphs.

The first phase of analysis was a content analysis (Berg, 2001) of the video-recordings. The analysis was based on coding for identifying video-sequences where simulation participants *identified ergonomics conditions*, and ordering these according to the *six work system entities*, step 1 and 2 in Fig. 3. The first author coded the videos for sequences where participants identified ergonomics conditions. By *identify*, we mean simulation participants articulated or visually showed ergonomics conditions, e.g. by discussing or acting possible future ergonomics challenges. By *ergonomics conditions*, we mean conditions that influence the well-being of the future healthcare professionals or the performance of the future work system. The identified sequences were transcribed as a combination of voice and visual conduct (Heath et al., 2010). We ordered the sequences according to which of the six work system entities the identified conditions related to. Some sequences were related to several entities and were thereby represented more than once, whereas other sequences only related to one entity. The total number of transcribed sequences, including duplicates, was 259 of the first case and 323 of the second case. The number of sequences per work system entity was normalized according to the total number of sequences per case.

The second phase of analysis was an inductive approached searching for patterns (Thomas, 2006) within the transcribed sequences of each work system entity, step 3 in Fig. 3. This resulted in identification of several subgroups of identified conditions within each work system entity. We assessed these subgroups on two levels: the *evaluation possibility* and the *influence of media attributes*, step 4 and 5 in Fig. 3. The *evaluation possibility* was assessed to find out whether the subgroups were purely identified ergonomics conditions or actually possible to evaluate. The following question guided the assessment: what is the possibility for the simulation participants to formulate a tangible design criterion from discussions of the identified ergonomics conditions? A tangible design criterion is a statement that a work system designer can directly apply, e.g. "this wall must be moved one meter as minimum, in order to get a proper work posture." A less tangible design criterion is a statement of a challenge to take into consideration during work system design, e.g. "there must be sufficient natural inflow of light for the work taking place." The *influence of media attributes* was assessed from the guiding question: how are the media attributes of fidelity and affordance influencing by either supporting or opposing the evaluation process?

4. Results

In this section, we present the results of the analysis: the ergonomic conditions identified and the evaluation possibility of the subgroups of identified conditions. The quantification of identified ergonomics conditions is presented in Fig. 4. The figure shows the distribution of video-sequences, where the participants identified conditions related to one or more of the six work system entities. The first case study of the full-scale mock-ups had a high percentage of identified ergonomics conditions related to *space* and *technologies & tools*. The second case study of the table-top models had a high percentage of identified ergonomics conditions related to *organization*. The exact distribution percentages of identified ergonomics conditions are presented in Appendix 1.

During the second step of analysis we realized that the simulation participants were not able to evaluate all the subgroups of identified conditions. This difference in evaluation possibility was especially interesting for the identified conditions related to *space* and *technologies & tools* in the first case, and *organization* in the

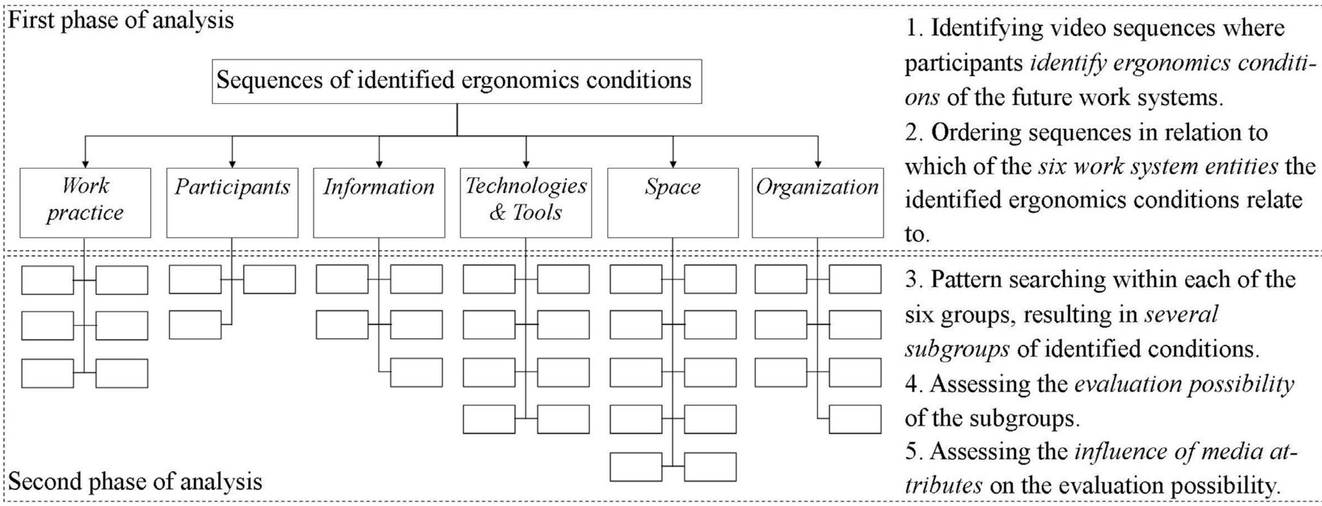

Fig. 3. The first and second step of analysis.

second case. We expected that the media's high capabilities in supporting identification of conditions related to these work system entities would additionally lead to high evaluation possibilities of these conditions. However, assessment of the subgroups revealed that not all identified conditions were able to be evaluated by the simulation participants. The fidelity level and affordance showed influence on the evaluation possibility.

In the situations where the participants were able to evaluate conditions, the fidelity related to that condition showed to be high. Furthermore, affordance of actions related to the condition under evaluation also showed to support the evaluation possibility. In the situations where the participants had difficulties in evaluating a condition, the media attributes showed not to influence the discussion. These discussions were triggered by the simulation media, but became detached from the media along the way, in the sense that the participants could not actively apply the media in their argumentation. Thereby, the participants did not reach a common agreement. The evaluation possibility and the influence of media attributes are presented in Table 4. For an overview of the evaluation possibility for subgroups of all six work system entities see Appendix 1.

5. Discussion

The results of the first step of analysis showed differences between the full-scale mock-ups and the table-top models in relation to the number of identified ergonomics conditions related to the six work system entities. The differences indicate that the two types of simulation media and their attributes support different ergonomics identification of the future hospital work systems. Furthermore, the media attributes additionally showed an influence on the evaluation possibility of the identified conditions, leading to the discovery that not all the subgroups of the work system entities could be evaluated. Considerations on the influence of media attributes are discussed in the following sections together with considerations on influencing contextual factors.

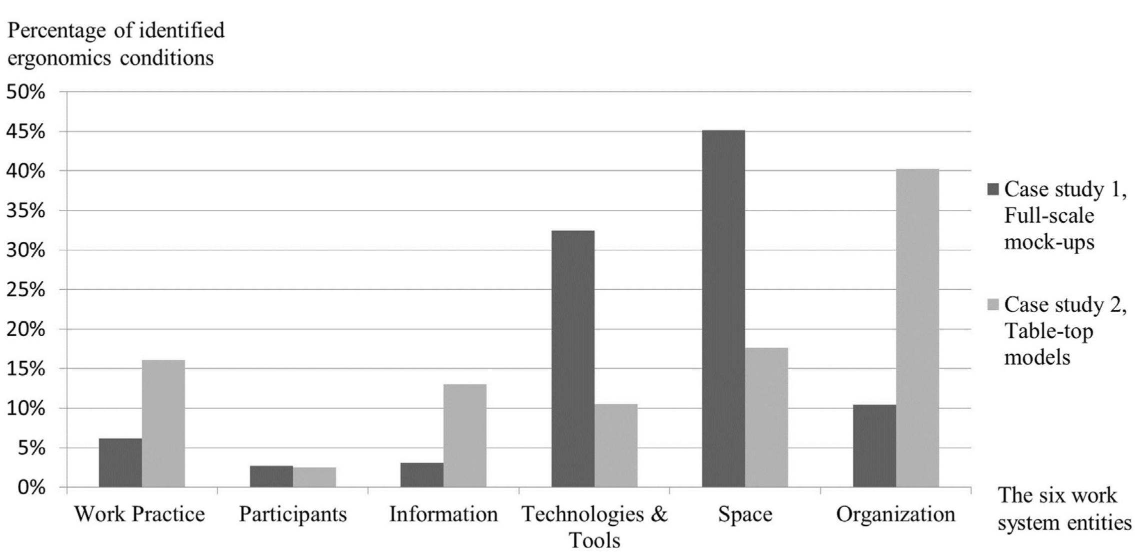

Fig. 4. The distribution per case study of the amount of video-sequences where the simulation participants identified ergonomics conditions in relation to the six work system entities.

5.1. Influence of media attributes on identification

The two simulation cases represented 'opposite' media in terms of media attributes. The full-scale mock-ups had a high fidelity level in regards to room dimensions, room layout, tool positions and tool dimensions. Furthermore, the full-scale mock-ups afforded configuration of the movable walls and operation of tools. These attributes connected to the high amount of identified ergonomics conditions related to the entities *technologies & tools* and *space*. In contrast, the table-top models showed low fidelity of the room dimensions and room layout, because the rooms were 'blackboxed' into cardboard boxes. However, the table-top models had a high fidelity of the overall organization and building layout of the future work system. Furthermore, the table-top models afforded room configurations and a helicopter view. These attributes connected to the high amount of identified ergonomics conditions related to the work system entity *organization*.

In existing studies applying full-scale mock-ups in PE activities and hospital design, the ergonomics conditions identified are also related to the entities *technologies & tools* and *space*. Existing studies applying table-top based simulation in manufacturing and building planning also identify conditions related to *organization*. The identified conditions are presented in Table 5. The purpose of Table 5 is not to identify all published studies of full-scale mock-ups and table-top based models, but to identify studies representing the application variety of these simulation media in participatory design activities.

In some of the existing studies, the authors reflect upon the simulation media fidelity in the form of detail level (Watkins et al., 2008) or the situation being 'too finished' (Bligård et al., 2014).

Table 4
The evaluation possibility of the subgroups of the three dominating work system entities, and the influence of the media attributes.

	Subgroups with high possibility for evaluation	Media attributes related to high evaluation possibility	Subgroups with low possibility for evaluation	Media attributes related to low evaluation possibility
Full-scale mock-ups				
Technologies & tools	- Execution of work is influenced by placement of technology within the room. - Execution of work is influenced by the dimensions of the tools and technologies. - Work posture is influenced by the tools and technologies.	High fidelity of dimensions of technologies and tools. Affording bodily operation of technologies and tools.	- Efficiency of work is influenced by the number of tools per room. - Efficiency of work is influenced by the types of tools within the room. - Efficiency of work is influenced by supporting tools for logistics and distribution of labor.	Low fidelity of technical systems and specific specialized instruments. Do not afford exploration of relations between several rooms.
Space	- Work practice is influenced by room shape. - Work practice is influenced by dimensions of interior. - Work posture and practice are influenced by room layout. - Area utilization is influenced by arrangement of interior.	High fidelity of room dimensions and layout. Affording bodily exploration and configuration of interior and room shape.	- Quality of work is influenced by noise level. - Psychosocial conditions are influenced by the room layout. - Physical conditions are influenced by light inflow. - Room layout and functions are influenced by external rooms' shapes and functions.	Low fidelity of material properties and light inflow. Do not afford exploration of a several rooms e.g. in a department.
Organization	—	—	- Division of labor influences the rooms' layout. - Organization of work tasks for obtaining efficiency.	Low fidelity of the overall department layout. Do not afford exploration of relations between several rooms.
Table-top models				
Technologies & tools	- Technologies for managing the overall patient flow. - Existing system problems are decreasing the efficiency.	High fidelity of the flows of patients and staff. Affording test and overview of several patient trajectories at the same time.	- The sufficient types of tools within the rooms influence the efficiency. - Technology functions supporting key work. - Team formation supporting tools for effective collaboration.	Low fidelity of the content of specific rooms. Do not afford test of the specific tools within the rooms.
Space	- The building layout influences the organization. - Decreasing walking distances for the workers. - Placement of rooms in relation to each other.	High fidelity of the overall department layout. Affording a helicopter view of the department and activities taking place.	- Interior layout supports work tasks. - Building shape influences the room shapes. - Numbers of each room type for covering the work tasks taking place.	Low fidelity of the layout of individual rooms. Do not afford exploration of single rooms, due to rooms being 'black-boxed' into cardboard boxes.
Organization	- Psychosocial conditions are influenced by work organization. - Organization of work is influenced by building layout. - Team formation is influenced by the organization and building layout. - Division of labor is a part of the work organization. - Work organization is influenced by effective coordination.	High fidelity of the overall building layout and functions. Affording a helicopter view of the relations and coordination between functions. Easy configuration of rooms.	- Efficient organization is influenced by relations to external functions. - Efficiency of work is influenced by the organization of activities in advance.	Low fidelity of relations to external functions outside the department. Do not afford exploration of tasks not predefined, such as the social relations in ongoing team formation.

Some studies actually refer to the concept of fidelity as influencing discussions among participants (Persson et al., 2014), being important in different design phases (Watkins et al., 2008) and being ‘good enough’ (Hallbeck et al., 2010). However, the connection between the fidelity and the actual identified ergonomics conditions has not been analyzed or defined.

The existing studies acknowledge in some ways that simulation media have different affordances. The full-scale mock-ups are referred to as giving a bodily experience (Bligård et al., 2014; Persson et al., 2014) and being flexible to use (Paquet and Lin, 2003; Peavey et al., 2012; Villeneuve et al., 2007). The table-top based models are discussed as providing an overview (Bligård et al., 2014; Ruohomäki, 2003; Savolainen, 1997). However, these properties are not defined as affordance, nor are they analyzed in relation to the conditions actually identified. Our study contributes to the existing studies by actually analyzing the connection between the identified ergonomics conditions and the media fidelity and affordance. We argue for the importance of considering this connection, when planning participatory simulation with the purpose of contributing to work system design by identifying ergonomics conditions.

5.2. *Influence of media attributes on evaluation*

In this study, we distinguish between identification and evaluation of ergonomics conditions. We define conditions with high evaluation possibility as fostering development of tangible design criteria, ready to be applied by work system designers. Whereas conditions with low possibility for evaluation have the characteristics of being less tangible and having the form of challenges to take into consideration during design. Existing studies on full-scale mock-ups and table-top based models show little consideration in regards to the form of the simulation outcomes, whether being directly applicable in design or challenges to take into account. Few studies define tangible design criteria (Hignett et al., 2010; Villeneuve et al., 2007; Watkins et al., 2008) and assess conditions (Daniellou et al., 2014; Hallbeck et al., 2010; Paquet and Lin, 2003; Ruohomäki, 2003). However, the development of these design criteria and assessment of the conditions are not analyzed in relation to the media fidelity and affordance.

During our analysis, we identified the fidelity of the full-scale mock-ups and table-top models as influencing the conditions possible to be identified. For example in the mock-ups, the ergonomics conditions relating to the high fidelity areas of room dimensions and room layout, illustrated evaluation possibility. In contrast, the ergonomics conditions relating to areas of the work system that the mock-ups manifested with a lower level of fidelity, were harder to evaluate. The mock-ups manifested e.g. the light and noise conditions of the hospital work systems to a low fidelity, because the mock-ups were situated in a hall, not reflecting the natural light and noise level. Thereby, the fidelity level manifested certain parts of the work system to a higher degree, seeming to support the evaluation of conditions related to these work system parts.

Furthermore, we identified the affordance of the full-scale mock-ups and table-top models as influencing the evaluation possibility. As an example, the table-top models' affordance of room configurations supported evaluation possibility of ergonomics conditions related to work organization and coordination between rooms and healthcare staff. However, ergonomics conditions related to e.g. external functions outside the simulated hospital department were harder to evaluate. This was possibly because the table-top models afforded configuration of rooms and functions defined to be situated within a specific department. In this way, the affordance related to certain parts of the work system demonstrated to support evaluation of these parts.

To increase the integration of the simulation outcome in the work system design, we argue for the importance of considering the form of the simulation outcome. In this manner, not simply aim at identifying ergonomics conditions, but actually evaluate these.

Table 5
Identified ergonomics conditions of existing studies of full-scale mock-ups and table-top based simulation.

	Full-scale mock-ups	Table-top models
Technologies & tools	- Movement of equipment/components (Hignett et al., 2010; Villeneuve et al., 2007) - Dimensions of equipment and furniture (Hignett et al., 2010; Steinfeld, 2004) - Work posture (Hallbeck et al., 2010) - Operation task time (Paquet and Lin, 2003) - Usability of tools and products (Paquet and Lin, 2003; Watkins et al., 2008) - Furniture and equipment (Peavey et al., 2012)	- Communication technology (Ruohomäki, 2003)
Space	- Depths, heights and positions (Bligård et al., 2014; Hignett et al., 2010; Peavey et al., 2012; Steinfeld, 2004; Watkins et al., 2008) - Usability of workstations (Paquet and Lin, 2003) - Physical requirements (Paquet and Lin, 2003) - Room dimensions and layout (Peavey et al., 2012; Villeneuve et al., 2007) - Materials (Peavey et al., 2012) - Interior designs (Persson et al., 2014) - Space sizes and planning (Steinfeld, 2004; Watkins et al., 2008)	- Plant layout (Daniellou et al., 2014; Riis, 1996) - Depths and relative heights (Bligård et al., 2014) - Spatial provision required (Ewenstein and Whyte, 2007)
Organization	- Distraction in work (Peavey et al., 2012) - Cognitive workload (Paquet and Lin, 2003)	- Work activities (Ruohomäki, 2003) - Human interaction (Ruohomäki, 2003) - Division of work and production schedule (Forssén-Nyberg and Makamäki, 1998; Ruohomäki, 2003; Savolainen, 1997) - Communication and cooperation (Forssén-Nyberg and Makamäki, 1998; Riis, 1996; Ruohomäki, 2003) - Unnecessary repetition (Ruohomäki, 2003) - Team reactivity (Daniellou et al., 2014) - Resources that are allocated (Daniellou et al., 2014) - Interdependence between departments (Forssén-Nyberg and Makamäki, 1998; Riis, 1996)

The ergonomics conditions of interest may vary according to the phase of the work system design process. The fidelity level should be high in relation to the elements that are of evaluation interest, and the affordance should support overview or configuration of these elements.

5.3. Influence of three contextual factors

This study argues that simulation media attributes influence the capability of supporting identification and evaluation of ergonomics conditions. Nevertheless, three contextual factors might also influence the identification and evaluation. The first contextual factor was the *scenarios*. The scenarios in the two cases were narratives of possible future work challenges and questions related to the work system represented by the simulation media. However, the two cases introduced the scenarios in different ways. In the first case, scenarios were continually developed during the simulation events by the healthcare professionals. In the second case, scenarios included a time factor and were defined beforehand by the simulation consultant and department managers. Existing studies show that scenarios stimulate the ideation in design (Carroll, 2000; Suri and Marsh, 2000). Thereby, the difference in the introduction of scenarios in the two cases of this study might have resulted in different stimulation of ideation, influencing the ergonomics identification and evaluation.

The second contextual factor was the *facilitation*. Both the cases had facilitators directing the progress of the simulation events. However, the facilitation style was different in each case. The facilitation in the first case was 'open' in the sense that the participants led the simulation event in an exploratory manner. The facilitation in the second case was regulated by the progress of the predefined scenarios and disturbances. Existing studies on facilitation in simulation as an education method show a high importance of the facilitation style in relation to the participants' educational profit (Clapper, 2014). Drawing on this research, the facilitation style may well be important for the profit of simulation as participatory ergonomics design method. Thereby, the difference in facilitation style of the two cases might have influenced the potential for ergonomics identification and evaluation.

The third contextual factor was the *participants*. The two cases included different participants in the sense of having different personal skills, backgrounds and experiences. Some of the participants were the future work system users, where other participants were designers of the future work system. Existing studies show the difficulty in choosing the 'best' participants in participatory processes (Reuzeau, 2001), indicating that different participants bring different perspectives to the process. In this way, the different participants of the simulation events might have brought different perspectives on the ergonomics identification and evaluation.

5.4. Methodological limitations of the study

The study is based on two cases of naturally occurring (Potter, 2004) simulation events. This gave in-depth understanding into the influence of simulation media on ergonomics identification and evaluation of these eight events. This in-depth understanding is obtained within the boundaries of the two case studies, which in some degree limit the generalizability (Thomas, 2011). However, findings of common patterns between cases are argued to be strengthened when the cases vary in maximum degree (Flyvbjerg, 2006; Neergaard, 2010). Despite the high variation between the type of conditions identified and evaluated, the comparative analysis actually showed a common pattern in how the fidelity and affordance influenced the identification and evaluation of ergonomics conditions. As verification, we have in addition compared the results of the two case studies with results of existing studies of full-scale mock-ups and table-top based models. The identified and evaluated conditions in the existing studies show to be consistent with our results. However, the connection between the media attributes and the conditions is not analyzed in the existing studies, as we aim for in this study. For further validation of this connection, we suggest research of other media such as virtual reality or small-scale mock-ups.

6. Concluding remarks

The aim of this study was to compare how the fidelity and affordance attributes of full-scale mock-ups and table-top models might influence the ability to identify and evaluate ergonomics conditions of future hospital work systems. This aim addressed the underresearched topic of the connection between simulation media attributes and the simulation outcome. Naturally occurring (Potter, 2004) simulation events in two Danish hospital building projects provided a unique opportunity for studying this connection from a case study perspective. The first case was based on full-scale mock-ups and the second case was based on table-top models.

Investigation of the two cases showed a difference between the identified and evaluated ergonomics conditions related to the future hospital work systems. The two types of media had a high level of fidelity in relation to different entities of the future work systems. Furthermore, the two media afforded actions in relation to different work system entities. In both cases, high fidelity and affordance of actions, relating to certain work system entities, appeared to support identification and evaluation of ergonomics conditions especially in relation to these entities. Existing studies of full-scale mock-ups and table-top based models showed identification of the same types of conditions. However, they did not analyze how media attributes influenced the identification. Neither did they address the importance of the form of the simulation outcome, in the sense of being identified challenges to take into account when designing or being tangible design criteria developed from ergonomics evaluation. This study emphasized the importance of considering the form of the outcome, and how the media attributes influence the possibility of reaching that outcome.

6.1. Implications for practitioners

We suggest the following implications for practitioners:

- When choosing simulation media in the planning of participatory simulation activities, practitioners should consider the relation between the intended simulation outcome and the attributes of fidelity and affordance.
- One media cannot support identification and evaluation of all types of ergonomics conditions. Thereby, the media attributes should target the areas of the work system, which are intended to be evaluated.
- The choice of simulation media should correspond with the present phase of the design process, where different phases require different ergonomics contribution. E.g. the concept design phase of buildings might require input about organization of functions, whereas the project phase might require input about detailed room layout.

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Appendix A

Table A.1
Results from the analysis of the two case studies.

Work system entities	Subgroups of identified ergonomics conditions: Conditions influencing the well-being and performance.	Numbers of transcribed sequences					Possibility for evaluation by the simulation participants
		Case 1	Case 2	Case 3	Case 4	Total	
Case study 1: Full-scale mock-ups							
Work Practice	- The work practice today	2	0	0	2	**16 (6%)**	Low
	- The room restricts the work practice	0	0	0	2		Low
	- The room supports efficient work practices	0	1	6	3		High
Participants	- Worker which are not central participants influence as well	0	0	2	3	**7 (3%)**	Low
	- The key participants are the main users	1	0	0	1		High
Information	- Discrete information sharing is required	4	0	0	0	**8 (3%)**	Low
	- The right information has to go to the right people for increased efficiency	3	0	1	0		Low
Technologies & Tools	- Efficiency of work is influenced by the number of tools per room	0	5	4	4	**84 (32%)**	Low
	- Execution of work is influenced by placement of technology within the room	2	3	5	4		High
	- Execution of work is influenced by the dimensions of the tools and technologies	0	0	2	6		High
	- Efficiency of work is influenced by the types of tools within the room	1	11	7	0		Low
	- Work posture is influenced by the tools and technologies	12	1	6	5		High
	- Efficiency of work is influenced by supporting tools for logistics and distribution of labor	4	1	1	0		Low
Space	- Quality of work is influenced by noise level	3	0	0	3	**117 (45%)**	Low
	- Psychosocial conditions are influenced by the room layout	4	0	0	0		Low
	- Work practice is influenced by room shape	6	1	1	16		High
	- Physical conditions are influenced by light inflow	2	1	2	0		Low
	- Work practice is influenced by dimensions of interior	3	0	8	1		High
	- Room layout and functions are influenced by external rooms' shapes and functions	2	2	0	0		Low
	- Work posture and practice are influenced by room layout	2	2	12	10		High
	- Area utilization is influenced by arrangement of interior	7	11	18	0		High
Organization	- Division of labor influences the rooms' layout	13	0	0	3	**27 (10%)**	Low
	- Organization of work tasks for obtaining efficiency	0	6	1	4		Low
Total						**259 (100%)**	
Case study 2: Table-top models							
Work practice	- Utilization of spare time for key work practices	2	3	5	1	**52 (16%)**	Low
	- Work practice frequency influences the work system	2	1	0	0		Low
	- The work practice today	1	0	2	4		Low
	- The time needed for work tasks	9	2	2	1		Low
	- People have personal preferences to work tasks	2	1	0	6		Low
	- Disturbances of work practices is decreasing the efficiency	1	2	5	0		High
Participants	- Number of special participants needed for the optimal quality of work	1	0	1	0	**8 (2%)**	Low
	- Experience of the participants needed in certain situations	1	1	0	1		Low
	- Different participants have different authority	0	0	2	1		High
Information	- Room layout support of informal communication	0	1	5	1	**42 (13%)**	High
	- The basic information needed in the work	0	7	3	3		Low
	- Information needed in unintended situations	8	0	5	9		High
Technologies & Tools	- The sufficient types of tools within the rooms influence the efficiency	1	3	3	1	**34 (11%)**	Low
	- Technologies for managing the overall patient flow	0	3	0	1		High
	- Technology functions supporting key work	0	1	1	2		Low
	- Existing system problems are decreasing the efficiency	3	0	1	1		High

Table A.1 (*continued*)

Work system entities	Subgroups of identified ergonomics conditions: Conditions influencing the well-being and performance.	Numbers of transcribed sequences					Possibility for evaluation by the simulation participants
		Case 1	Case 2	Case 3	Case 4	Total	
	- Team formation supporting tools for effective collaboration	6	2	1	4		Low
Space	- The building layout influences the organization	6	4	6	2	**57 (18%)**	High
	- Decreasing walking distances for the workers	2	3	2	2		High
	- Interior layout supports work tasks	2	3	4	0		Low
	- Building shape influences the room shapes	0	1	2	0		Low
	- Placement of rooms in relation to each other	5	1	3	1		High
	- Numbers of each room type for covering the work tasks taking place	2	2	4	0		Low
Organization	- Psychosocial conditions are influenced by work organization	0	5	10	5	**130 (40%)**	High
	- Efficient organization is influenced by relation to external functions	4	1	0	0		Low
	- Organization of work is influenced by building layout	3	16	11	4		High
	- Team formation is influenced by the organization and building layout.	8	7	6	0		High
	- Division of labor is a part of the work organization	9	3	8	9		High
	- Efficiency of work is influenced by the organization of activities in advance	2	3	2	1		Low
	- Work organization is influenced by effective coordination	5	4	1	3		High
Total						**323 (100%)**	

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APPENDIX G: CONFERENCE PAPER 2

INTERNATIONAL DESIGN CONFERENCE - DESIGN 2016
Dubrovnik - Croatia, May 16 - 19, 2016.

THE PROCESS OF PARTICIPATORY ERGONOMICS SIMULATION IN HOSPITAL WORK SYSTEM DESIGN

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Keywords: Participatory Ergonomics, Hospital, Work System Design

1. Introduction

When designing new hospitals, engineers and architects take design decisions that will influence the work taking place in the new hospital. The building design influences organization of functions, communication between workers and patients, application of medical technologies and conduction of work practices. All these parts together constitute the hospital work system. A work system "comprises two or more people working together, interacting with technology within an organizational system that is characterized by an internal environment (both physical and cultural)" [Kleiner, 2006]. Thereby, design of new hospital buildings also includes design of new hospital work systems.
Participatory ergonomics simulation (PES) is a method to design new hospital work systems. It is based on involvement of workers in simulation and design of their own future work system [Daniellou, 2007]. PES is applied within the field of Human Factors and Ergonomics and draws on principles from the field of Participatory Design. The purpose of PES is to design ergonomics work systems by applying a participatory design approach. Ergonomics work systems means that the work system support of both human well-being (e.g. physical, cognitive etc.) and overall performance (e.g. quality, efficiency etc.) [International Ergonomics Association, 2015].
PES consists of four elements. The first element is a simulation medium, which visualizes and represents the future work system to be designed, e.g. an architectural blueprint of a future building. The second element is scenarios of the future work that will take place in the new work system. The scenarios are defined beforehand. The third element is participation of workers, who are the future users of the new work system. The fourth element is facilitation of the PES.
These four elements are combined during PES events either as narrative simulation or experimental simulation. Narrative simulation is based on participants discussing scenarios on how to conduct the future work in the new work system [Daniellou, 2007]. Experimental simulation is based on participants acting out how the future work could be conducted in the new work system [Daniellou, 2007]. In both narrative and experimental simulation, facilitation of the process is crucial in order to guide the process and ensure an ergonomics work system design. Despite of this, a thorough understanding of the process of PES has gained low attention. However, to understand the PES process is important when planning and facilitating PES, with the intension of reaching ergonomics work system design.

1.1. Existing research and aim of study

Existing research on participatory design processes have highlighted four different perspectives of the participatory design approach. An overview is presented in Table 1 and related to the elements of PES.

Table 1. Four different perspectives on participatory design

Perspectives	Keywords for the perspectives	Relation to PES elements
Visualization by media	Prototypes, models, games etc. have the role as mediators between participants [Andersen and Broberg, 2015; Béguin, 2003; Bratteteig and Wagner, 2012; Broberg et al., 2011; Dindler, 2010; Lucero et al., 2012; Steen et al., 2013; von Hippel, 2009, 1994]	First element; simulation media, which visualize the future work system and are applied in the PES.
Experimenting and reflecting	Exploration and experimentation of possible design solutions from a human-centred design perspective [Binder and Brandt, 2008; Broberg and Edwards, 2012; Brown, 2009, 2008; Taffe, 2015; Valkenburg and Dorst, 1998] Review and evaluation of possible solutions [Andersen and Broberg, 2015; Détienne et al., 2012; Taffe, 2015; Valkenburg and Dorst, 1998]	Second element; scenarios that are applied in experiments of the future work in PES.
Different participants' contributions and perspectives	Sharing of experiences, perspectives and information by participants from different domains [Béguin, 2003; Bratteteig and Wagner, 2012; Broberg and Hermund, 2007; Garrigou et al., 1995; McDonnell, 2009; Scariot et al., 2012; von Hippel, 2009, 1994; Xie et al., 2015] Conflict, tension and negotiation as process drivers [Béguin, 2003; Bowen et al., 2013; Buur and Larsen, 2010; Détienne et al., 2012; Dolonen and Ludvigsen, 2013; Patel et al., 2012; Taveira, 2008; Xie et al., 2015]	Third element; participating workers with different backgrounds contribute with different experiences in PES. They also have different interests that possibly can foster conflicts etc.
Collaborative space	Metaphorical and temporary collaborative spaces fostering innovation [Binder and Brandt, 2008; Bratteteig and Wagner, 2012; Brodersen et al., 2008; Dindler, 2010; Lucero et al., 2012]	Fourth element; facilitation, which involves establishment of a temporary and metaphorical space for the PES to take place.

The assumption of this study is that the different perspectives are interrelated and together constitute the process of PES. Therefore, this study investigates the interrelations of the perspectives with the aim of developing a framework describing the process of PES in hospital work system design. The intension of the framework is to assist practitioners in planning and facilitation of PES in hospital work systems design. The framework is developed based on a case study of two cases of PES in hospital work systems design. Analysis of observations and interviews resulted in identification of five interconnected elements that together constitute the PES framework. In the following, the case study and framework are presented and discussed together with the implications for ergonomics interventions and practitioners.

2. Methodology

The case study methodology [Thomas, 2011] applied focusing on two cases of PES in hospital work system design. The cases were selected on a maximum variation criterion [Thomas, 2011] in relation to variation in the design phase where PES was applied. The first case applied PES in the form of table-top simulation in the early design phase of a new outpatient department. The second case applied PES in the form of blueprint simulation in the last design phase of a new intensive care unit (ICU). The maximum variation strategy was applied because of the argument that identification of commonalities in maximum variating cases strengthens the findings [Thomas, 2011].

2.1. The case of table-top simulation

This case was part of designing a new outpatient department at a major Danish hospital. As a part of the early and conceptual design phase, healthcare workers from the existing outpatient department were invited to participate in four PES events as presented in Table 2. The aim was to develop a conceptual design proposal for the layout of the new outpatient building and the work system going to take place in the building. The PES events were a public private collaboration between the outpatient department, ergonomics researchers, simulation consultants and consultants from industry. The PES events were facilitated by one of the simulation consultants. The simulation medium applied in the PES events was a table-top model. This model constituted of cardboard boxes, LEGO figures, marker pens and an A0 poster as shown in Figure 1. The cardboard boxes were placed on the poster and represented the future examination rooms in the outpatient department. Placing the cardboard boxes in different ways, different building layouts could be visualized. The LEGO figures depicted healthcare workers and patients. The simulation participants were each assigned a role and a LEGO figure corresponding to their professional background, e.g. the physician was assigned the physician LEGO figure. The researchers and the consultants from industry were assigned patient LEGO figures.

Table 2. The four PES events constituting the case of table-top simulation

	PES event 1	PES event 2	PES event 3	PES event 4
Focus	Separate examination and conversation rooms	One examination room per two conversation rooms	Multifunctional examination rooms and staff area	Development of multifunctional examination rooms
Partici-pants	One physician, one nurse, one medical secretary, one consultant from industry, two simulation consultants, three researchers.			Three nurses, three physicians, two con-sultants from industry, one simulation consul-tant, three researchers.

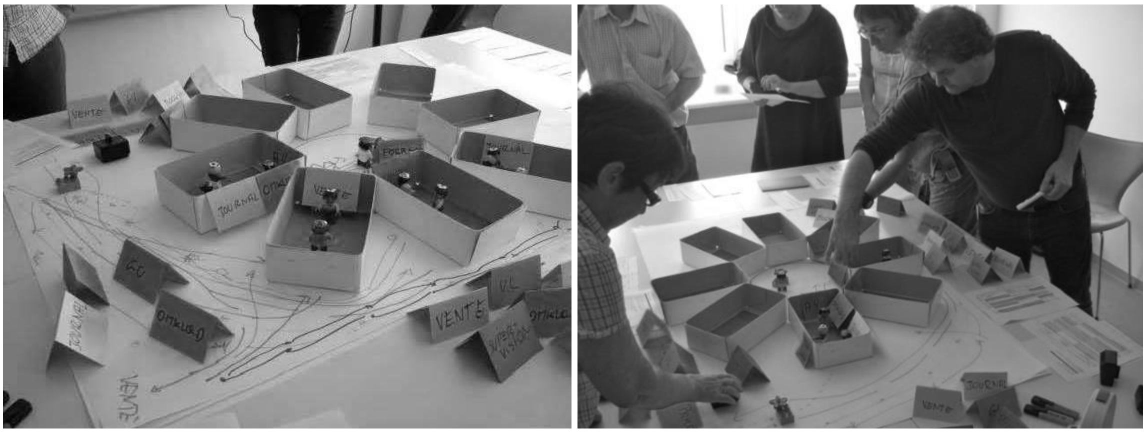

Figure 1. Left: the table-top model. Right: a table-top simulation

The facilitating simulation consultant and the outpatient management had beforehand defined scenarios based on different types of patient examinations. The scenarios consisted of a list of actions in relation to the examinations. Each action had a simulation time assigned as a third of real time. The simulation participants acted out the scenarios by applying egg-timers for timing the different actions of the scenarios. During the scenario acting, the participants moved the LEGO figures around the table-top model and drew the movement on the A0 poster using the marker pens.

After each scenario acting, the simulation consultant facilitated a discussion among the participants in relation to obtained ergonomics insights. The discussion led to proposals of design changes, which were implemented by changing the configuration of the cardboard boxes and explored through new scenarios acting.

2.2. The case of blueprint simulation

The second case was part of designing a new intensive care unit (ICU) at a smaller Danish hospital. The physical department was designed during a previous design process involving both designers and workers from the existing ICU. However, in the last design phase, right before the workers moved into the new department, the work system of communication methods, technology application and work practices, still needed a detailed design. As part of the work system design, healthcare workers from the existing ICU were invited to participate in PES. This study focuses on four of the PES events, as presented in Table 3. The events were arranged by the executive nurse and the nurse in charge of work practice development. Furthermore, the PES was facilitated by two organizational consultants from the regional human resource department. The simulation medium applied in the four PES events was blueprints combined with LEGO bricks and LEGO figures as illustrated in Figure 2. The blueprint was A0 size and illustrated the design of the new ICU. The LEGO figures depicted healthcare workers and patients and the LEGO bricks illustrated hospital beds.

Table 3. The four PES events constituting the case of blueprint simulation

	PES event 1	PES event 2	PES event 3	PES event 4
Focus	Testing and developing the future work system taking place in the new ICU			
Partici-pants	Two nurses, Three coordinating nurses, One physiotherapist, One executive nurse, One work practice development nurse, Two organisational consultants.	Three nurses, One coordinating nurses, One service assistant, One medical secretary, One executive nurse, One work practice development nurse, Two organisational consultants.	Four nurses, Six coordinating nurses, One occupational the-rapist, One executive nurse, One work practice development nurse, Two organisational consultants.	Three nurses, Three coordinating nurses, One occupational therapist, One service assistant, One medical secretary, One execu-tive nurse, One work practice development nurse, Two organi-sational consultants.

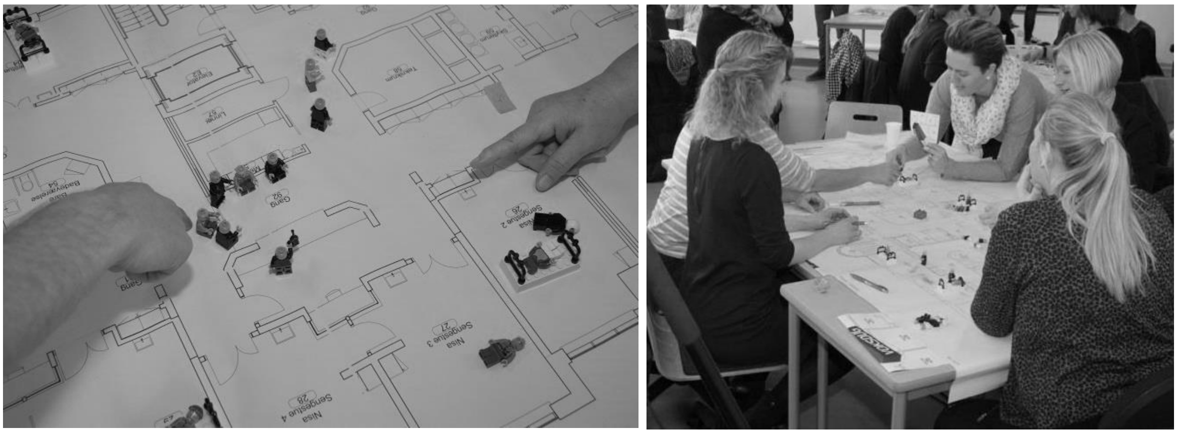

Figure 2. Left: the blueprints and LEGO figures. Right: a blueprint simulation.

The nurse in charge of developing work practices had beforehand created five scenarios. The scenarios were everyday situations, which likely would happen in the new ICU work system. The simulation started by one of the participants reading aloud a scenario. This led to the participants placing LEGO figures on the blueprint to depict the healthcare workers and patients as described in the scenario. The scenarios included a series of questions on how to handle the everyday situation in the new work system. These questions were the foundation of exploring different ways of designing and organizing the work practices. The exploration was first based on the participants moving the LEGO figures on the blueprint in accordance with the scenarios. This led to discussions of possible solutions on the scenarios, which led to new scenarios acting with the LEGO figures. After each scenario, the facilitators asked the participants to reflect and write down suggestions for the future work system.

2.3. Data collection and analysis

Data collection was based on observations of the PES events and interviews with selected simulation participants. The observations were based on an observation guide focusing on the PES process of each event. The interviews were semi-structured [Kvale, 1996] and based on an interview guide focusing on the participants' experiences of the PES events. The interview respondents are listed in Table 3. The observation notes and interview transcriptions were analysed through coding. The initial coding protocol was based on the four perspectives of participatory design identified in the existing research in section 1.1. The coding protocol was revised concurrently with the analysis through an iterative process of analysing data and evaluating the protocol [Miles and Huberman, 1994]. The analysis resulted in identification of five elements across the two cases. These five elements and their interrelations were proposed as a framework describing the PES process in hospital work system design.

Table 3. Interview respondents

Table-top simulation	Blueprint simulation
One nurse, one medical secretary, two consultants from industry, two simulation consultants, two researchers, one physician.	Two coordinating nurses, one service assistant, one organizational consultant, one executive nurse, one work practice development nurse.

3. Results

The identified five elements and their interrelations are proposed as a framework describing the process of PES in hospital work system design. The framework is presented in Figure 3 and elaborated in the following sections.

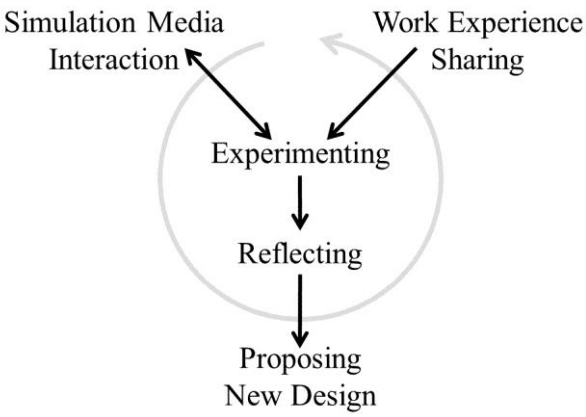

Figure 3. The proposed PES framework

3.1. Experimenting with the future

The observations showed that a central part of the PES was participants exploring and experimenting with different designs of the future hospital work system. Therefore, experimenting was identified as the central elements in the framework.

Experimentation was as well a topic receiving attention in the interviews. Participants described PES as a process of testing: 'We tried out different designs… the advantage was that we tested and orchestrated several different working procedures and then selected the one we liked the best.' - Medical secretary, table-top simulation. Experimentation also included a discussion part: 'The important thing was that it [the blueprint simulation] encouraged the "what-if" discussions'- Executive nurse, blueprint simulation. Thereby, experimentation supported both testing and discussion of future work system design.

3.2. Interacting with the simulation media

From the observations of the PES events, the two types of experiments showed to be tightly related to the simulation media: the table-top models and the blueprints. The simulation media visualized the future work system design: ‘The blueprint and the LEGOs made it concrete and visual, and then you reach it [a new design proposal] together.’ – Coordinating nurse, blueprint simulation. The visualization ability of the simulation media was observed to foster the testing and the “what-if” discussions. By configuring the cardboard boxes in different ways, the participants of the table-top simulation tested several different work system design possibilities related to the building layout and organisation. By distributing LEGO figures and LEGO bricks in different ways at the ICU blueprint, the participants of the blueprint simulation could discuss different ways of designing the future work system of the work practices. Several of the respondents described that the application of simulation media distinguished from the situation of “only sitting and talking”. It [the table-top model] was concrete … and realistic.’ – Nurse, table-top simulation. ‘This [the blueprints] was practical, and you could start playing with it.’ – Executive nurse, blueprint simulation. ‘…The LEGO figures turned alive, and you became the role you were playing’ – Consultant from industry, table-top simulation. Thereby the simulation media added an element of “serious play” to the PES.
Whether the experiments led to interaction with the simulation media or revers was not clear from the analysis. Therefore, the identified connection between these two elements was illustrated as a two-way arrow in the proposed framework.

3.3. Sharing of work experiences

The observations revealed that during the experimentation, the different participants contributed with knowledge and experiences from their own work and professional background. The respondents emphasized the importance of having participants with different backgrounds. The experience sharing was described as: ‘We obtained different perspectives on the same matter, so you got a sense of the other participants. The nurses think as their profession and secretaries think as their professions.’ - Physician, table-top simulation. ‘I heard one [a service assistant] say that service assistants also had a role at the morning meetings. [Somebody asked] “But why do they actually have that?” [The assistant answered] “Because we are also a part of the planning”, “ah, okay I see…”‘ - Executive nurse, blueprint simulation.
A common topic in the interviews was that the contribution and sharing of work experiences resulted in understanding of other professions’ challenges and needs in the future work system. ‘I heard that people said; “Okay, that's how you see it. That was not how I saw it”‘- Work practice development nurse, blueprint simulation. Thereby, the sharing of experiences contributed to the testing and discussion in the experiments and the relation between these two elements was thereby illustrated in the proposed framework by a one-way arrow.

3.4. Reflecting on the experiments

The experimentation was observed to lead to the participants reflecting on the new insights obtained from the experiments. The insights were often realizations about the ergonomics consequences of the work system design explored during the experiments. The realizations were described as: ‘There were occasionally some whoops'. Like “oops, but that's not possible, because so and so”. For example, the waiting time could not be avoided, if there was a young doctor, who had to wait for an experienced doctor.’ - Medical secretary, table-top simulation. Such whoops-realizations also led to new experiments.
Furthermore, reflections also supported participants realizing that their personal assumptions on the future hospital work system design were perhaps not relevant. An example of this is described as: ‘Apparently, there had been “myths” about the distances in the new building would be very far. But when they [the healthcare workers] stood by the blueprint, they saw that this was actually not a problem. So the story [the myths] could suddenly be stripped away‘ - Organisational consultant, blueprint simulation. In this way, the PES also showed a change management purpose by being an initiative in decreasing resistance to change in relation to the implementation of new hospital work

systems. The relation between the experiments and reflections was illustrated as a one-way arrow in the framework.

3.5. Proposing new design

The PES events included the participants and the facilitators documenting proposals for new design criteria and new designs of the future hospital work system. The criteria and design proposals developed from the participants' reflections was a reaction for improving the ergonomics challenges realized. In the table-top simulations the participants proposed a new outpatient department layout and new work procedures to minimize walking distances and improve utilization of time. In the blueprint simulation the participants proposed a new work organization and new work practices to minimize the psychosocial workload on the nurses and improve coordination. These criteria and design proposals were the outcomes of the PES.

The formulation of design criteria and development of new designs were observed to be a joint activity among the participants. Also described by a respondent: 'It was funny that we all realized the same solution. Namely, that we had to move the coordinating function. We were all agreeing on that, and we had not talked about it [that solution] before.' – Coordinating nurse, blueprint simulation. The joint activity also resulted in trade-offs in relation to the different participants' interests. '…We each had our own "I-want-that"-approach…that did not make it easier, because then we had to move around with the elements each of us wanted.' - Nurse, table-top simulation.

The relation between the reflections and development of new design proposals was illustrated as a one-way arrow in the framework.

3.6. An iterative process

The five elements identified and interrelated were observed not to be as linear as indicated in the previous sections. Instead, the process was highly iterative, and the participants went through the elements several times. This iteration is illustrated as a circular arrow in the background of the proposed framework.

4. Discussion

This study investigated the interrelations of the elements in PES with the aim of developing a framework describing the process of PES in hospital work system design. The elements of the framework are discussed in the following sections.

4.1. Resources for experimenting

The analysis showed that PES in the two cases was based on experiments. However, the experiments showed to be highly supported by the visualization capabilities of the simulation media and the shared experiences of the participants. Thereby, the simulation media and sharing of work experiences can be seen as resources for the experiments.

The resource ability has been recognized in existing participatory design studies. Interaction with visualizing artefacts in the form of prototypes and games has been described as experimental [Binder and Brandt, 2008; Broberg et al., 2011; Taffe, 2015]. Furthermore, sharing of workers' experiences has been identified in experimental activities [Béguin, 2003; Broberg et al., 2011]. However, these experiment resources have not been related to reflections on ergonomics consequences. Thereby, experiments are not the final goal of participatory processes such as PES, but are a mean to foster the outcome of PES in the form of new ergonomics work system design.

4.2. Reflections by non-professional designers

Existing studies on participatory design, such as PES, have identified the benefits of reflection in participatory processes. Reflections are conceptualized as reflexive practice, as continual reviewing and as evaluation of design moves [Détienne et al., 2012; Taffe, 2015; Valkenburg and Dorst, 1998] and is described as the central move towards a design solution. But the existing studies have mainly concentrated on collaborative design between professional designers. This study shows that reflections also are essential in participatory design groups of non-professional designers. This opens for the possibility that other parts of reflexive design practice of professional designers might also be relevant in participatory design processes with non-professionals.

4.3. Proposing new design as a joint activity

The reflections showed to lead to participants proposing new work system design. The proposal was developed as a joint activity including negotiation and trade-offs, which can be related to the existing studies on group dynamics and negotiation in participatory design [Béguin, 2003; Bowen et al., 2013; Buur and Larsen, 2010; Détienne et al., 2012; Dolonen and Ludvigsen, 2013; Patel et al., 2012; Taveira, 2008; Xie et al., 2015]. The proposal of new design in PES is thereby influenced by group dynamics. However, the existing studies have mainly concentrated on the group dynamics and not how this is encouraged through experiments and reflections as identified in this study.

4.4. The application of the PES framework

The framework developed from the two case studies is intended to be a tool in planning and facilitation of PES in ergonomics interventions in hospital work system design and other related sectors. The PES method is relevant in both corrective, preventive and prospective ergonomics interventions [Robert and Brangier, 2009]. Incremental changes through correction of identified problems in existing work systems can be tested through PES. Prevention of ergonomics problems in new design can be introduced through PES as presented in the two case studies. New prospective innovations in future work systems can be developed through PES initiatives.

The three ergonomics approaches influence the elements: simulation media and experience sharing. In corrective ergonomics, a simulation medium visualizing the incremental changes to a high degree of detail is important for conducting realistic simulations. Furthermore, participation of workers with experiences in the existing problems is relevant for PES in corrective ergonomics. The preventive ergonomics can benefit from a flexible and malleable simulation medium in order to support experimentation with many different solutions. Here participation of the future workers is relevant. Prospective ergonomics innovations would include more than workers as participants, but also marketing, professional designers and researchers.

These examples show that the PES framework can support practitioners reflecting on the elements of the PES process when planning PES in different types of ergonomics interventions. Furthermore, understanding of the different elements' interconnections in the PES framework is relevant for practitioners that are facilitating PES. The PES framework shows that the facilitator should encourage the participants to reflect on experiments, because reflections are related to development of new design proposals. This can ensure the progression of the PES process towards the intended outcome.

4.5. Limitations and further research

This study is a case study of two PES cases, both contributing to design of new hospital work systems. The results are thereby drawn from an in-depth understanding of the PES processes of these two cases. This limits the generalizability of the results [Thomas, 2011]. However, the results can be an opportunity for learning from cases and applying principles of this learning in other related contexts [Thomas, 2011]. The limited generalizability opens up for further research into participatory design processes such as PES. Further research could benefit from including more empirical data. This data could be additional case studies or other types of data for the purpose of triangulation [Thomas, 2011]. Furthermore, testing of the PES framework in planning and facilitation of PES in other sectors can result in further development and detailing towards a more solid framework and increase the knowledge about the application.

5. Conclusion

The aim of this study was to develop a framework describing the process of PES in hospital work system design. The framework was developed from analysis of two cases of PES: table-top simulation of an outpatient department and blueprint simulation of an ICU. With outset in four different

perspective of participatory design, observations and interviews from the two cases were analysed. During the analysis the four perspectives developed into five elements together constituting a framework describing the process of PES across the two cases. The five activities were as follows. The simulation media in the form of table-top models and blueprints were together with the participants' experiences from the existing work the resources of the simulations. Through interaction with the simulation media and sharing of professional experiences the participants engaged in experiments of the future work system. The experiments were in relation to both acting of the future work and discussion on how to carry out the future work. Both types of experiments showed to lead to participants reflecting. The reflections were related to how the design of the future work system would influence the future work and ergonomics conditions. The reflections resulted in the participants proposing a new work system design through negotiations of new design proposals or formulation of new design criteria. The identified elements and their relations were illustrated and proposed as a framework describing the process of PES in hospital work system design.
The framework can potentially be applied in other work system design contexts e.g. work system design in production companies. The intension is that the framework can assist in planning and facilitation of PES processes. Understanding of the elements and their interrelations strengthens the facilitation of efficient and goal oriented PES processes.

5.1. Implications for practitioners

Three proposals of implications for practitioners' planning and facilitating PES in work system design:

- Participants with different professional backgrounds are essential for obtaining different experiences and intensions contributing to the experiments. However, be aware that the process of reaching jointly decided design proposals has to be facilitated through negotiations.
- Consider to apply simulation media that support experiments of different work system design. Thereby, the simulation media should visualize the parts of the work system of interest in the simulation and be flexible in use.
- Including small breaks in the experimentation can potentially leave time for reflections on the ergonomics consequences of the work system design. The reflections potentially lead to participants proposing new design and formulating design criteria.

Acknowledgement

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APPENDIX H: JOURNAL PAPER 2

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A framework of knowledge creation processes in participatory simulation of hospital work systems

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ABSTRACT
Participatory simulation (PS) is a method to involve workers in simulating and designing their own future work system. Existing PS studies have focused on analysing the outcome, and minimal attention has been devoted to the process of creating this outcome. In order to study this process, we suggest applying a knowledge creation perspective. The aim of this study was to develop a framework describing the process of how ergonomics knowledge is created in PS. Video recordings from three projects applying PS of hospital work systems constituted the foundation of process mining analysis. The analysis resulted in a framework revealing the sources of ergonomics knowledge creation as sequential relationships between the activities of simulation participants sharing work experiences; experimenting with scenarios; and reflecting on ergonomics consequences. We argue that this framework reveals the hidden steps of PS that are essential when planning and facilitating PS that aims at designing work systems.

Practitioner Summary: When facilitating participatory simulation (PS) in work system design, achieving an understanding of the PS process is essential. By applying a knowledge creation perspective and process mining, we investigated the knowledge-creating activities constituting the PS process. The analysis resulted in a framework of the knowledge-creating process in PS.

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Participative ergonomics; health care ergonomics; process mining; knowledge creation; work systems

1. Introduction

Designing new hospital workplaces does not only include design of the physical buildings. The physical building is tightly connected with how the work is organised, how workers communicate, how workers apply different technologies and how workers conduct work tasks. These interconnected elements together form a hospital work system (Carayon et al. 2015; Hallock, Alper, and Karsh 2006; Holden et al. 2013). A work system has been defined as '… a system in which human participants and/or machines perform work using information, technology, and other resources to produce products and/or services for internal or external customers' (Alter 2006).

The design of hospital work systems has been shown to influence health care workers' well-being and performance, resulting in impact on patient safety and quality of care (Hignett et al. 2013). Therefore, the design of hospital work systems has to support the work and the associated workers. Participatory ergonomics and simulation have been stated as two methods for designing work systems supporting the work and workers (Waterson et al. 2015). Participatory ergonomics (PE) involves workers in interventions and the design of their own future work system (Neumann and Village 2012; van Eerd et al. 2010; Xie, Carayon, Cox, et al. 2015). The advantage of PE is that the workers' knowledge of the existing work system contributes to the design of the new work system, and involvement of workers in the early design of work systems has shown financial benefits (Hendrick 2008). Simulation tools can have different forms but always involve modelling the existing or the future work system (Hettinger et al. 2015). The advantage of simulation is that different work system designs can be evaluated without the necessity for resource-demanding interference with the existing 'real world' work system. The rationale of both PE and simulation is that ergonomics challenges can be identified and improved during the design process, instead of being corrected after implementation, which often involves high costs.

A method combining the advantages of PE and simulation is participatory simulation (PS). PS is based on the principle that workers are involved in simulation of their future work system by application of simulation media that model the future work system (Daniellou 2007). The benefits of PS have been shown to be innovation of the future work system (Broberg and Edwards 2012); evaluation of

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the future ergonomics conditions (Andersen and Broberg 2015); detection and improvement of design properties that would lead to hazards or malfunctioning (Daniellou 2007); and smoothening of the implementation process (Daniellou 2007). The outcome of PS is often in the form of worker feedback that can function as new design specifications intended to be communicated to work system designers and integrated in the design (Barcellini, Van Belleghem, and Daniellou 2014; Béguin 2014; Broberg, Andersen, and Seim 2011; Daniellou 2007; Österman, Berlin, and Bligård 2016). The worker feedback has been shown to take several different forms (Österman, Berlin, and Bligård 2016), and is highly influenced by the fidelity of the simulation medium applied (Andersen and Broberg 2015).

This introduction to PS shows that the existing research has mainly focused on analysing the outcome of PS and not the process of creating this outcome. We argue that without understanding this process, we risk blindly planning and facilitating PS events. In the context of hospital work system design, it means that we remove hospital workers from their core area, for participating in PS events to create new design specifications, without really knowing the process we are planning and facilitating. Therefore, this study will investigate the process of PS. In order to do this, we suggest applying a knowledge creation perspective. In this way, we view PS as a process of creating new ergonomics knowledge in the form of new design specifications for the future work system to support both the human well-being and the overall system's performance.

1.1. Study aim

When applying a knowledge creation perspective to PS, we highlight how participating workers contribute with individual professional experiences, competences and knowledge (Béguin 2014; Daniellou 2007) to create new design specifications. The workers' professional knowledge is often difficult to put into words because it often has a 'tacit' nature and is thereby difficult to verbalise (Garrigou et al. 1995; Norros 2014). Norros (2014) indicates that PS and the application of objects such as simulation media is a relevant method for converting tacit knowledge into explicit knowledge. To shed light on this knowledge transformation and knowledge creation process of PS, *the aim of this study was to develop a framework describing the process of how ergonomics knowledge is created in PS.* We define a framework as a way of describing different elements and the general relationships among these elements (Ostrom 2011). We define a process as being a set of interrelated activities all contributing to a common goal. We define ergonomics knowledge as the outcome of PS in the form of new design specifications. The intention of the framework is to support ergonomists in planning and facilitating PS events.

1.2. The study context

The context of the study is hospital work system design. The outset is the current renewal process of the Danish hospitals, aiming at increasing efficiency and quality of care. Renewal of the hospital buildings includes building redesign and design of new hospital work systems to be employed in the new buildings. To assist the renewal process, the Danish Regional Councils have funded several innovation centres that involve health care workers from the existing hospitals in events that can be characterised as PS. The purpose is to benefit from the health care workers' professional knowledge of the existing hospital work systems to develop design specifications, and communicate these to the actors making design decisions about the new hospital work systems. These actors are hospital management, hospital planners, consulting architects and consulting engineers. The PS phenomenon currently occurring in the Danish innovation centres provides a unique opportunity to investigate the creation of work system design specification in PS as a process of creating ergonomics knowledge.

2. Theoretical basis of knowledge creation

The knowledge creation perspective originates from organisational theory studies. Knowledge is defined as a 'mix of framed experiences, values, contextual information and expert insight …' (Davenport and Prusak 2000). The term *knowledge creation* has been applied in explanations of how companies could sustain innovative initiatives (Nonaka 1991). In this context, knowledge is recognised as a corporate asset of the organisation (Davenport and Prusak 2000). Knowledge creation has been defined as the process of converting individual tacit knowledge into explicit common knowledge and back again into tacit common knowledge in the organisation (Nonaka and Takeuchi 1995).

2.1. PS from a knowledge creation perspective

Viewing PS as a knowledge-creating process has not previously been introduced in the human factors and ergonomics field. Nevertheless, the knowledge creation perspective can bring a new frame of understanding to PS and other related participatory methods, because PS events include several of the same key elements as knowledge creation in an organisation does. In the following, we present three key elements and outline three assumptions that functioned as the initial frame of analysis of this study.

2.1.1. First key element: interaction with objects in the form of simulation media

PS includes the application of and interaction with simulation media in the form of, e.g. mock-ups, prototypes and game boards that represent the initial design of the future work system (Daniellou 2007). These simulation media have been shown to fill the roles as mediators between the different participants (Béguin 2003; Broberg, Andersen, and Seim 2011; Daniellou 2007).

From a knowledge creation perspective, objects, such as the simulation media, have been shown to have the ability to mediate communication and sharing of knowledge between different actors, and thereby across boundaries (Carlile 2002). Furthermore, interaction with objects has been shown to foster new insights and ideas through the phenomenon of 'back-talk' (Schön 1983). 'Back-talk' happens when an actor interacts with or manipulates materials such as objects and then realises new insights based on the consequences of the interaction. The role of objects in knowledge creation in organisational studies may indicate that simulation media also have a role in knowledge creation in PS. Accordingly, our first initial assumption was that the activity of *interacting with objects in the form of simulation media* is a part of the knowledge creation process in PS.

2.1.2. Second key element: engagement in tests and experiments

The simulation media are applied in what can be characterised as tests of different design scenarios of the future work system (Barcellini, Van Belleghem, and Daniellou 2014; Broberg, Andersen, and Seim 2011; Garrigou et al. 1995). The tests have been shown to be either *narrative*, where participants describe how the future work can be carried out in the new work system, or *experimental*, where participants act out the future work (Barcellini, Van Belleghem, and Daniellou 2014; Daniellou 2007).

From a knowledge management perspective, the tests can be related to the principles of reflective practice (Schön 1983) and of trial and error (Nonaka 1994). Reflective practice is an iterative process consisting of four iterative phases: framing the problem in a certain way, naming relevant factors of a situation, generating moves towards a solution and reflecting on the outcomes of the moves (Schön 1983). Trial and error is a similar iterative process that happens when different actors combine their individual knowledge to develop new concepts through 'experimentation' (Nonaka 1994). The importance of experimenting in knowledge creation in organisational studies may also be important in knowledge creation in PS. Accordingly, our second initial assumption was that the activity of *engaging in tests in the form of experiments* is a part of the knowledge creation process in PS.

2.1.3. Third key element: sharing knowledge in the form of experiences

Participating workers from different domains share perspectives and confront individual experiences (Broberg, Andersen, and Seim 2011; Garrigou et al. 1995; Xie, Carayon, Cartmill, et al. 2015). This has the consequences of conflicts, splitting, and negotiation (Béguin 2003; Taveira 2008) or shared awareness, consensus and group decisions (Patel, Pettitt, and Wilson 2012; Taveira 2008; Xie, Carayon, Cartmill, et al. 2015).

From a knowledge management perspective, the sharing of perspectives and experiences can be related to the phenomenon of knowledge sharing. Knowledge sharing happens when individual and often tacit knowledge is converted into explicit and sharable knowledge, also called externalisation (Nonaka 1994). Knowledge can have different forms, where experiences are a central form. Experience is defined as 'what we have done and what has happened to us in the past' (Davenport and Prusak 2000) and is individual contextual knowledge. The importance of sharing knowledge, in the form of experiences, in the process of knowledge creation in organisations may also be important in the context of knowledge creation in PS. Accordingly, our third initial assumption was that the activity of *sharing knowledge by referring to work experiences* is a part of the knowledge creation process in PS.

3. Methods and procedures

We studied the PS events taking place in three different innovation centres, each related to a hospital renewal project in Denmark. These three projects were selected based on a maximum variation criterion (Flyvbjerg 2006) in relation to the PS types defined by the simulation medium. Thereby, the three projects applied three different simulation media: table-top models, full-scale mock-ups and blueprints. The rationale of the maximum variation criterion was to strengthen findings of commonalities across the PS events of the three projects (Cresswell 2013). In this way, we sought to identify commonalities in the knowledge creation process across the three different PS types.

3.1. Procedures of the PSs

The three projects and the PS types are summarised in Table 1, and the procedures for each PS type are presented in the following sections.

3.1.1. Table-top simulations

The table-top simulations of the first hospital design project were initiated by the Danish Capital Region Innovation Centre, and were based on table-top models. The models consisted of A0-sized poster (33.1 × 46.8 in), where LEGO®

Table 1. The three hospital design projects applying PS.

PS type	Aim of application of PS	PS events	Types of participants	Application of scenarios	Facilitators	Facilitation style	Documentation of PS outcome
Table-top simulation	Apply PS to contribute to design of a new outpatient department building at a major hospital and test simulation methods in health care innovation	Four PS events with duration from 1.5 h to 2 h	Chief surgeon, physician, nurses, medical secretaries, consultants from industry, researchers in ergonomics	Developed beforehand by the management and the facilitator including a list of work tasks, including simulation time of each task	Clinical simulation consultant	The facilitator solely directed the PS	Participating researcher sketched the agreed department layout and took notes on the agreed organisation
Full-scale mock-up simulation	Apply PS to test standard room proposals for a major new hospital intended to replace two existing hospitals. The testing was intended to inform the architectural design process	Four PS events with duration from 45 min to 1 h	Medical secretaries, executive medical secretaries, executive nurses, staff members from hospital management, staff members from project division, IT consultants, hospital orderlies, technical department employees, architects, engineers	Identified in an introductory meeting and continually developed by the PS participants during the PS events	Centre facilitators with occupational health and safety background, and clinical background	Facilitation in an open manner where the facilitators were cautious, and encouraged the participants to take initiative	Centre facilitators sketched the agreed room layout and took notes to form a description
Blue print simulation	Apply PS for supporting the process of moving into a renovated intensive care unit at a small hospital and contributing to design of the work system planned to take place in the new facilities	Four PS events with duration of 2 h	Nurses, coordinating nurses, physiotherapists, service assistants, medical secretaries, occupational therapists, charge nurses	Developed beforehand by the work practice development nurse, and were applied as an outset of the PS events	Work practice development nurse, facilitator from region	Facilitation in an open manner where the facilitators were cautious time managers, and encouraged the participants to take initiative	Simulation participants took turns in taking notes

figures and cardboard boxes were arranged; see Figure 1. The LEGO® figures depicted patients and health care professionals. The cardboard boxes illustrated rooms of the future outpatient department. The boxes were placed in different configurations to illustrate concepts for future building layout. The different layouts also included various ways of organising the work. The variety of layouts and work organisations were the foundations for each of the four PS events.

The participating health care professionals from the existing outpatient department were selected by the department management. The goal was to include representatives from the three main employee groups. The health care professionals were the most active in the simulations, whereas the consultants and researchers were mainly observing and only occasionally participating.

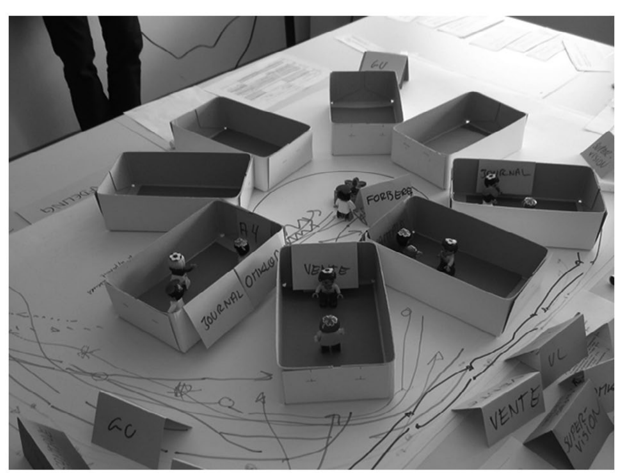

Figure 1. The table-top model after scenario playing. Source: Ole Broberg.

The work tasks applied as scenarios were assigned simulation time as a third of real time. For simulating the scenarios, each of the participants was assigned a role and a LEGO® figure reflecting his or her professional background, and the group was supplied with egg timers for managing the simulation time of the scenarios. The participants moved the LEGO® figures around the table-top model and simultaneously drawing the movements on the A0-sized poster (33.1 × 46.8 in). After each scenario acting, the facilitator introduced a debriefing where the participants had the opportunity to discuss the insights obtained. This discussion often led to proposals of new work organisation or department layout in the form of a reconfiguration of the cardboard boxes, leading to yet another scenario being acted and so on.

The participants agreed on a concept for the future outpatient department layout and work organisation. The notes and sketches documenting the concept were typed up as a part of a report intended to communicate the PS outcomes to architects, engineers and other researchers in health care innovation.

3.1.2. Full-scale mock-up simulations

The full-scale mock-up simulations of the second hospital building project occurred in an innovation centre established by the owner of the hospital planning project. The mock-ups consisted of movable chipboard walls, large foam bricks and standard hospital interior; see Figure 2. The mock-ups were constructed by the two centre employees prior to the PS events on the basis of architectural blueprints of hospital room proposals provided by the consulting architects.

The participating health care professionals were selected by the centre employees on the criteria of having worked in the rooms to be tested through full-scale mock-up simulations. The employees from the project owner organisation, and engineers and architects from the consulting companies, participated in order to contribute with technical insights.

The PS events started with an introductory meeting where the centre employees introduced the participants to the architectural room proposal. In the meeting, the participants discussed possible ergonomics challenges and work scenarios. The scenario acting and discussion in the subsequent full-scale mock-up simulation resulted in the centre employees adjusting the mock-ups and the participants retesting the mock-ups, iteratively leading to new adjustments.

The simulations continued until a room design supporting an ergonomic work system was obtained. Documenting sketches and descriptions of the agreed room design were intended to serve as an input to the project owner organisation, the engineers and the architects managing the further hospital design.

3.1.3. Blueprint simulations

The blueprint simulations were part of an initiative of one of the Danish Regional Councils to establish a regional consulting service in the form of an innovation centre. The centre assisted in the process of moving into a new intensive care unit (ICU) by introducing blueprint simulation two months before the staff had to move into the new facilities. The blueprint simulations were based on A0-sized (33.1 × 46.8 in) blueprints of the future ICU including LEGO® figures, as illustrated in Figure 3. The blueprints were the final version of the new ICU layout designed by a team of architects and engineers. The LEGO® figures depicted patients and health care professionals at the ICU.

Figure 2. The full-scale mock-up of chipboard walls and foam bricks. Source: Simone Nyholm Andersen.

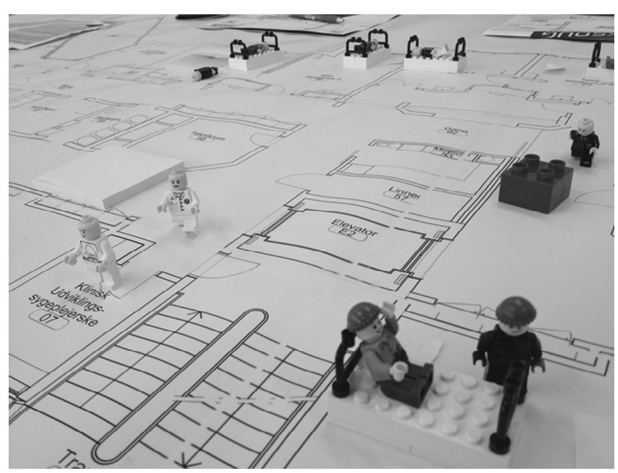

Figure 3. Blueprints of the ICU LEGO® figures and bricks applied in the PS events. Source: Simone Nyholm Andersen.

The participating health care professionals were selected by the ICU management based on the criteria of involving health care professionals from the five main employee groups.

The applied scenarios stated typical work situations, e.g. two patients are unrestful and require attention, though it is time for the morning meeting for the nurses; what would you do? The scenarios triggered the participants to visualise the situation by applying the blueprint and the LEGO® figures. To solve the scenarios, the participants discussed and tested different possible solutions by moving the LEGO® figures around on top of the blueprint. The participants' discussions and acting of scenarios led to new questions and challenges, which iteratively encouraged new discussions and acting.

The blueprint simulation resulted in the participants agreeing on new ways of organising the work practices and the work systems. The participants' notes on the new organisation and work practices intended to serve as input for the ICU management, architects and engineers.

3.2. Data collection

The data collected were based on video recordings of the PS events. The first author observed and recorded the full-scale mock-up simulations and the blueprint simulations. The second author observed, occasionally participated in, and recorded the table-top simulations. Video was recorded by applying a fixed camera with the purpose of acquiring a distant view of the PS events, and thereby recording the interactions of the different participants (Heath, Hindmarsh, and Luff 2010). An advantage of the fixed camera was also that the camera drew less attention from the simulation participants.

3.3. Data analysis

The data analysis was based on three steps, as illustrated in Figure 4. The three steps are elaborated in the following three sections.

3.3.1. Video coding

In the first analysis step, we applied the three assumed knowledge creation activities of PS defined in Section 2.1 as a frame of analysis in the form of an initial coding protocol. The video recordings of the first PS events of each of the three hospital design projects were coded in order to identify the video segments in which participants engaged in the three activities. The coded video segments were transcribed as a combination of both audio and visual conduct (Heath, Hindmarsh, and Luff 2010). The transcriptions were subsequently thoroughly examined to evaluate the initial coding protocol. From that examination, the initial coding protocol was expanded to 5 main activities and 13 sub-activities as illustrated in Figure 4 and presented in Appendix A. The expanded coding protocol was applied in the coding of the remaining video recordings. This resulted in a total of 3415 coded video segments.

3.3.2. Process mining

In the second analysis step, we applied process mining to explore the relations between the 13 sub-activities identified in the first analysis step. Process mining is related to process analysis, which is the study of processes from a view of what is really happening and not from the view of predefined procedures (van der Aalst and Weijters 2005). Process mining is based on the utilisation of data from event logs (van der Aalst and Weijters 2005). Event logs refer to information systems that companies use to manage business processes. These systems include retrospective

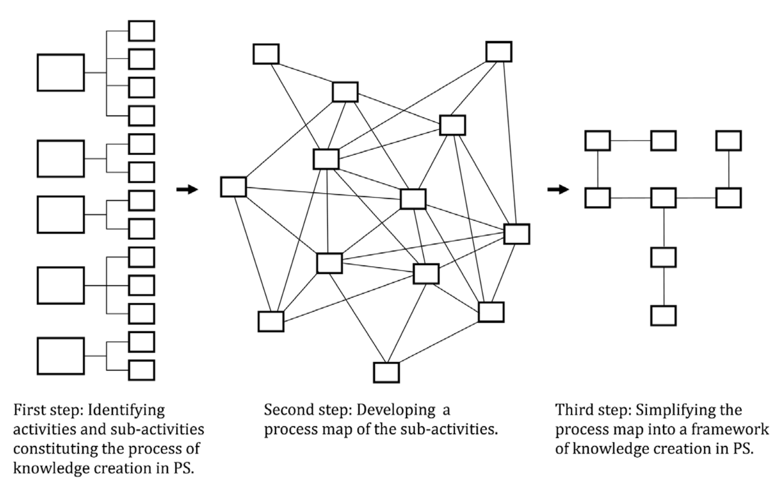

Figure 4. The three steps of analysis. Source: Simone Nyholm Andersen.

data on the conducted activities in relation to specific business processes, where each process instance is described as a case. The data are based on timestamps, consisting of a start- and end-time of each conducted activity per case. In this study, we expanded the understanding of event logs to include our coding of the video recordings. The coded video segments were all described by a sub-activity and a timestamp. Furthermore, each coded video segment was part of 1 of the 12 PS events defined as cases. This left us with 12 cases and a list of sub-activities per case including timestamps.

In process mining, the cases in the form of sub-activities and timestamps are combined into a process map illustrating a 'representative' of the behaviour seen in the event log (van der Aalst 2011). This map is created through the analysis of patterns of activities across the cases. The patterns involve both the sequence of activities and whether activities happen at the same time. Consequently, if activity B often happens after activity A or if activity B often happens at the same time as A, a causal dependency is assumed and a connection is visualised in the process map (van der Aalst 2011). For creating the process map, we applied the software Disco® by Fluxicon (Eindhoven, The Netherlands). From the 12 PS events of sub-activities and timestamps, we created a process map of the sub-activities representing the knowledge creation process across the 12 PS events. The process map is illustrated in the second analysis step in Figure 4. This process map shows a nest of connections in the form of sequential relationships between the sub-activities.

3.3.3. *Simplification of process map*

In the third step of analysis, we applied the principles of aggregation and abstraction (Günther and van der Aalst 2007) to simplify the process map. Aggregation is intended to 'limit the number of information items displayed' in the process map (Günther and van der Aalst 2007). This was done by clustering the sub-activities that were related to the same main activity. Abstraction is to omit information that is 'insignificant in the chosen context' (Günther and van der Aalst 2007). This was done by omitting connections that had low frequency. The frequencies of the connections between the sub-activities are presented in Appendix B. We chose to omit connections with a frequency constituting less than 1.3% of the total number of frequencies of the connections between all sub-activities. In addition, we also left out the repetition connections in the sense of self-looping of sub-activities.

Furthermore, we investigated which sub-activities occurred at the same time. These were identified per case through the analysis of overlap of the timestamps and are presented in Appendix C. The sub-activities, having overlaps constituting more than 4.4% of the total number of overlaps between all sub-activities, were visually indicated on the simplified process map. The simplification of the process map resulted in a framework (Ostrom 2011) describing the knowledge creation process across the 12 PS events as illustrated in the third step of analysis in Figure 4.

4. A framework of knowledge creation in PS

The developed framework is presented in Figure 5. The framework includes five main activities and eight sub-activities. The frequencies of the connections, in the form of sequential relationships, are indicated by the thickness of the arrows. The frequency of each connection is described as a percentage of the total number of frequencies of the connections between all of the sub-activities in the process map. Some sub-activities often occurred at the same time and thereby did not constitute a sequence. This is visualised as dashed boxes in the framework. In the following sections, we review the framework, provide empirical examples of central sequential relationships and interpret these in relation to the knowledge creation perspective.

4.1. *The relationship between 'asking other participants', 'explaining own work' and 'what-if discussions'*

The activity, *sharing work experiences*, had two dominating sub-activities: *asking other participants* and *explaining own work*. The *explaining own work* led to *what-if discussions*, which were a sub-activity of the *experimenting*. In the *what-if discussions*, participants discussed future scenarios related to how to design the new hospital work system. The discussions often started with 'what if …' and were focusing on either the physical elements of the work system, e.g. buildings or interior positioning, or organisational aspects of the work system, e.g. how to divide work. An example of the sequential relationship between the three sub-activities is presented in Table 2.

4.1.1. *'Explaining own work' as knowledge externalisation*

The relationship between the *explaining own work* and *what-if discussions* had a high frequency. Thereby, *explaining own work* can be seen as a trigger of *what-if discussions*. To enable this triggering, the shared work experiences from the *explaining own work* had to be understandable to other participants. To be understandable, the work experiences in the form of individual knowledge had to be explicit, which implied externalisation of the individual knowledge (Nonaka 1994). Thereby, when participants externalised their individual work experiences, they started engaging

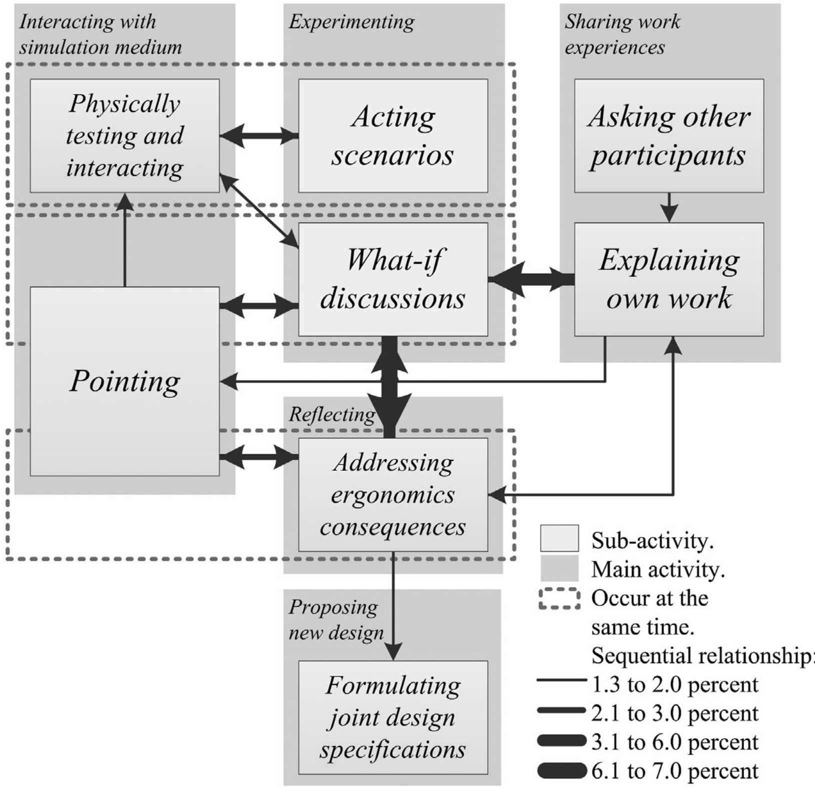

Figure 5. A framework of the knowledge creation process in PS. Source: Simone Nyholm Andersen.

Table 2. Example of the sequential relationship between *asking other participants*, *explaining own work* and *what-if discussions*.

From blueprint simulation PS events 1		
The scenario simulated is how a nurse, assigned to receive a new patient, can manage to prepare medication for the patient. The medication has to be prepared in the medication room located in one part of the ICU. The new patient is placed in another location of the ICU. The challenge is that the nurse has to constantly monitor the new patient, meaning that the nurse cannot leave the patient to travel to the medication room		
Asking other participants	Physiotherapist:	*Addresses a question to the participating coordinating nurse 1:* 'Can you leave the [bed]room now?'
Explaining own work	Coordinating nurse 1:	'No, I can't ...'
	Coordinating nurse 2:	'I don't think we should be the only one to receive. The way we do it now is that we allocate two persons' (Refers to the fact that one of the persons can leave the room to prepare medication)
What-if discussions	Coordinating nurse 1:	'What if one [nurse] from one of the good [less urgent] patients could take over here? And then I could go'
	Nurse:	'Then the coordinator could look after the good patient [in the meantime]'
	Coordinating nurse 1:	'Yes, you cannot take care of the most complicated [patient] and be coordinator [at the same time]'

in experiments in the form of *what-if discussions* based on the externalisations.

4.2. The relationship between 'acting scenarios', 'physically testing and interacting' and 'what-if discussions'

The *experimenting* activity had two sub-activities: *acting scenarios* and *what-if discussions*. In the *acting scenarios*, participants acted out scenarios that had been defined beforehand or that continually developed during the PS events. The acting was in contrast to the *what-if discussions* in which participants discussed the scenarios but did not perform them. The *acting scenarios* often happened at the same time as participants were *physically testing and interacting* with the simulation medium, leading to *what-if discussions*. An example of this sequential relationship between the three sub-activities is presented in Table 3.

Table 3. Example of the sequential relationship between *acting scenarios*, *physically testing and interacting,* and *what-if discussions*.

From table-top simulation PS event 3		
In this simulation example, the intention is to reduce the number of times a patient has to move between rooms in the outpatient department. In the existing department, the patient moves from the waiting area to the physician in the examination room and to the nurse in the conversation room. In this scenario, the patient goes directly to a free examination room when arriving to the department. Furthermore, the physician and nurse do not have settled rooms, but move from room to room, and thereby from patient to patient		
Acting scenarios, Physically testing and interacting		*An egg-timer rings*
	Medical secretary: (acting patient)	'Now I'm done'
	Physician: (acting physician)	'Then I say goodbye, and then I go out here and start writing' *Moves the LEGO® figure out of the examination room (cardboard box) into the staff area on the A0-sized poster (33.1 x 46.8 in)*
	Nurse: (acting nurse)	'Yes, and we [the nurse and the patient] have talked, so the patient can just go home now. Goodbye'
	Medical secretary: (acting patient)	'Yes, goodbye …' *Grasps her LEGO® figure and moves the figure out of the examination room (cardboard box) towards the reception on the A0-sized poster (33.1 x 46.8 in). She draws the movement on the poster using the marker*
What-if discussions	Physician:	'But what if a new patient had arrived [in the meantime]? Then she could just go directly to a free room, right?'

4.2.1. 'Experimenting' for combining externalised knowledge

The *physically testing and interacting* sub-activity was shown to be the link between the *acting scenarios* and *what-if discussions*. The relationship between these three sub-activities was shown to be bidirectional, meaning that the *acting scenarios* and *what-if discussions* occurred in iterations. The iterations related to the trial-and-error processes (Nonaka 1994) based on actors engaging in experiments and combined their externalised knowledge into new concepts (Nonaka 1994). Thereby, the iterative *experimenting* was a process in which the participants combined their externalised knowledge.

4.3. The relationship between 'what-if discussions', 'pointing' and 'physically testing and interacting'

What-if discussions were a sub-activity of *experimenting*, and happened often at the same time as the *pointing*, which was a sub-activity of *interacting with simulation medium*. In this way, the participants applied the simulation medium in their discussions by pointing at different parts of the medium. The discussions and pointing led to the participants *physically testing and interacting* with the simulation medium by grasping and moving parts. *Physically testing and interacting* was the second sub-activity of *interacting with simulation medium*. The interactions were shown to foster new *what-if discussions*. As a result, an iterative loop between these three sub-activities was identified, and an example is presented in Table 4.

4.3.1. Two modes of simulation media interaction for knowledge combination

Pointing and *physically testing and interacting* were two modes of simulation media interaction. Each of them happened at the same time as each of the sub-activities of *experimenting*, as indicated with dashed boxes in the framework. *Experimenting* was the activity of participants combining externalised knowledge. To achieve this, participants had to communicate. Relating to the mediating abilities of objects (Carlile 2002), the simulation medium and the two modes of interaction can be seen as central resources for the communication between the participants having different professional backgrounds. Thereby, the modes of interactions are also resources for the combination of externalised knowledge.

4.4. The relationship between 'what-if discussions', 'addressing ergonomics consequences', 'pointing' and 'formulating joint design specifications'

The *what-if discussions* led to *addressing ergonomics consequences*, which were a sub-activity of *reflecting*. The *addressing ergonomics consequences* happened when participants assessed and evaluated the ergonomics consequences of the scenario explored in the *what-if discussions*. At the same time, as the participants were *addressing ergonomics consequences*, they were *pointing* at parts of the simulation medium. Often, the *addressing ergonomics consequences* led backwards to the *what-if discussions*, resulting in an iterative loop. However, sometimes this loop led to *formulating joint design specifications*, which was a sub-activity

Table 4. Example of the loop between *what-if discussions*, *pointing*, and *physically testing and interacting*.

From full-scale mock-up simulation PS event 3		
This simulation example is related to how cabinets in a depot for bed wards can be placed. The challenge is to obtain the most efficient utilisation of the square metres and at the same time provide the best conditions for work within the depot. The work within the depot is related to handling of stored assistive technologies, e.g. wheelchairs		
What-if discussions, Pointing	Project division staff:	'What if we placed cabinets all the way down in the middle': *Stands within the mock-up and points across the room to indicate where the cabinets could be placed* 'Then we could walk down one or the other side' *First pointing at one side and then at the other side of the imaginary row of cabinets*
	Executive nurse 1:	'So, what you are saying is that we can have cabinets here ...' *Points across the room in the same direction as the project staff*
	Executive nurse 2:	'... and then we can open them from both sides?' *Points at each side of the imaginary row of cabinets*
Physically testing and interacting	Executive nurse 1:	'Yes, that might work. Let's try that'. *Grasps several large foam blocks and places them in the middle of the room to symbolise the row of cabinets* ...
What-if discussions	Executive nurse 3:	'But what if we have to place a wheelchair in here?'

of *proposing new design*. In the *formulating joint design specifications*, participants were together agreeing on and defining design specifications for the future hospital work system. Two different types of design specifications were identified. The first type consisted of tangible and precise design suggestions, e.g. specific placement of patients or interiors. The second type involved less tangible focus points, e.g. possible challenges about light inflow or psychosocial stress. The tangible design suggestions had the purpose of guiding the work system design, where the focus points were intended as challenges to be taken into account in the design. An example of the sequential relationship between the four sub-activities is presented in Table 5.

4.4.1. Experiment-reflection loop as reflective practice in knowledge creation

The identified loop between *what-if discussions* and *addressing ergonomics consequences* shows an experiment-reflection loop. This loop relates to the third and fourth phases of reflective practice (Schön 1983): *generating* moves towards a solution and *reflecting* on the outcomes. Here, the *what-if discussions* are discussions of possible design moves towards an ergonomic work system design, and *addressing ergonomics consequences* involves the reflections on the consequences of these possible design moves. The *pointing*, taking place at the same time as *addressing ergonomics consequences*, can be related to the phenomenon of 'back-talk' (Schön 1983), where the participants' interactions with the simulation media are a resource for realising and reflecting on the ergonomics consequences. The frequency of the loop between the *what-if discussions* and the *addressing ergonomics consequences* was the highest compared with the other connections in the framework. Thereby, the reflective practice was a core part of the knowledge creation process in the PS activities.

4.4.2. The jointly created ergonomics knowledge

The experiment-reflection loop was shown to develop into participants *formulating joint design specifications*, which we see as the created knowledge. However, the frequency of the connection from *addressing ergonomics consequences* to *formulating joint design specifications* was observed to be relatively low compared with the frequencies in the experiment-reflection loop. Investigation of the low frequency revealed that when participants were *addressing ergonomics consequences*, they engaged in *what-if discussions* on several different ways of redesigning the work system in order to address the negative consequences. This resulted in addressing challenges, which led to new *what-if discussion*. The participants engaged in several iterations before they reached an agreement and formulated joint design specifications. Thereby, the knowledge created in PS is a result of comprehensive experiment-reflection loops.

5. Discussion

The developed framework describes the sub-activities and sequential relationships constituting the knowledge creation process in PS of hospital work systems. The intention of the framework was to support ergonomists in planning and facilitating PS events. The framework supports this planning by revealing the activities and sub-activities constituting the knowledge creation process of PS. Thereby, the ergonomist knows which activities to plan for. The planning includes selection of simulation medium

Table 5. Example of the sequential relationship of *what-if discussions*, *addressing ergonomics consequences*, *pointing* and *formulating joint design specifications*.

From blueprint simulation PS event 3		
The challenge of this simulation is to place an isolation patient in the new ICU. The patient has to be in isolation because of an infection. The aim is to place the patient in a bedroom close to the sluice room, in order to minimise the distance that the waste from the isolated patient has to be transported. When decreasing the distance, the risk of passing the infection on to other patients is decreased, and the amount of walking for the nurses is decreased		
What-if discussions, Pointing	Nurse 1:	'What if we place him here?' *Points at one of the bedrooms in the blueprint*
Address ergonomics consequences, Pointing	Coordinating nurse:	'Yes, then he is close to the sluice room, to the depot, to all the things'. *Points first at the sluice room and then to the depot on the blueprint*
What-if discussions	Nurse 2:	'But it depends on which other patients we have at the moment'
	Coordinating nurse:	'Then we could also place him in bedroom number eight?' (Bedroom Number 8 is at the other side of the building)
Pointing, Address ergonomics consequences	Nurse 1:	'Yes, he can be placed there or over here …' *Points at the first proposed bedroom and then at Bedroom 8*
		'… because then [in both cases] he is close to the sluice room and the depot'. *Points at the sluice room and the depot*
Formulating joint design specifications	Nurse 2:	'So we all agree that he has to be placed in that end of the building'
	Occupational therapist, Nurse 1:	'Yes'

to support both modes of media interaction; preparation of scenarios to support both types of experiments; and selection of participants with relevant professional experiences. The framework supports facilitation by revealing the connections between the sub-activities constituting the knowledge creation process of PS. The connections show which sub-activities form sequences leading to the created knowledge in the form of *formulating joint design specifications*. In the facilitation, the ergonomist then knows which activities to encourage and monitor in order to create new ergonomics knowledge. In this way, the framework reveals the previous hidden steps of the knowledge creation process in PS. In the following sections, we will discuss the contributions and further research of this study.

5.1. The knowledge creation perspective and the process mining method

Existing ergonomics studies have addressed and applied the principles of experiential learning and knowledge sharing (e.g. Béguin 2003; Garrigou et al. 1995; Neumann, Dixon, and Ekman 2012), which relate to knowledge creation. However, viewing participatory activities such as PS as knowledge creation processes has not previously been introduced in the ergonomics field. The present study thereby contributes by showing how the theoretical knowledge creation perspective assists in drawing attention to the sub-activities of the PS process.

Several ergonomics studies have introduced a system perspective based on interconnected elements (e.g. Carayon et al. 2015; Hallock, Alper, and Karsh 2006) that relate to the process mining method. Despite the commonalities, process mining is still a novel method in the ergonomics field. In this study, the process mining supplemented the knowledge creation perspective by showing the connections between the knowledge creation activities, and thereby contributes by revealing the hidden steps of the PS process. Furthermore, the process mining provided an opportunity for conducting a deep and thorough empirical analysis.

5.2. The variations between the PS events

The PS events investigated in this study applied different simulation media, scenarios and facilitation styles, and involved different types of participants. The possible influences of the variations are discussed in the following sections.

5.2.1. The simulation medium

The fidelity of the simulation medium has been shown to influence PS outcome (Andersen and Broberg 2015; Bligård, Österman, and Berlin 2014). Furthermore, simulation participants are known to prefer some media over others (Österman, Berlin, and Bligård 2016). Based on this, the simulation media in this study might have influenced the knowledge creation process, especially in relation to the two modes of media interaction. However, when comparing the three types of PS in relation to the two modes of interaction, we could not identify a clear pattern of difference. This could mean that the three simulation media all supported both modes of interaction. However, we will emphasise that this does not necessarily mean that the medium does not matter when creating ergonomics knowledge. The medium should still support both modes of interaction, e.g. blueprints without LEGO® figures would not give rise to participants grasping and moving parts in the *physically testing and interacting* activity. This might also be the reason for simulation participants rating 2D blueprints as less preferable than full-scale mock-ups, which afford the *physically testing and interacting* activity to a greater extent (Österman, Berlin, and Bligård 2016).

5.2.2. The scenarios and the facilitation style

The scenarios and the facilitation in the PS events were related. When scenarios were applied as outset for the PS, the events were facilitated in an open manner. When scenarios were applied as manuscripts, a more directed facilitation style was applied. Existing studies on scenario application show that scenarios stimulate ideation (Carroll 2000), and existing studies on facilitation of simulation in education show that the facilitation style influences participants' educational profit (Clapper 2014). Therefore, the scenarios and facilitation style of the PS in this study might have influenced the knowledge creation process. We expected the influence in relation to the two types of *experimenting*: *acting scenarios* and *what-if discussions*. Both rely on scenarios and require facilitation in different ways. When comparing the knowledge creation process of the three PS types, a small excess of *acting scenarios* happened in the table-top simulation, which applied scenarios as manuscripts and had a more directed facilitation style. However, the *what-if discussions* still occurred and resulted in experiment-reflection loops. This indicates that a scenario's application and facilitation style might influence the type of experiments taking place in PS. Furthermore, we suggest that further research be conducted on the influence of scenarios and facilitation on the knowledge creation process of PS.

5.2.3. The simulation participants

The simulation participants of the different PS events varied. Existing studies indicate that some participants are more skilled than others in engaging in participatory processes (Reuzeau 2001; von Hippel 2009). Therefore, the differences of participants might have influenced the knowledge creation process. In some events, the diversity of the participants in relation to their professional background was limited. This was especially true in relation to the full-scale mock-ups. A low diversity could have resulted in fewer shared work experiences because the participants already knew each other's work due to their mutual professional background. We expected to see this in the *asking other participants* and *explaining own work* activities. However, the analysis did not show a clear pattern of difference between the PS events of low and high participant diversity. Nevertheless, we have to take into account that the involvement of workers in work system design has been a tradition in Scandinavia and workers are thereby culturally prepared for engaging in participatory processes. This might be different in other national contexts and requires further research.

5.3. Limitations and transferability

This study is based on three hospital design projects consisting of 12 PS events. This yielded an in-depth understanding of these specific findings, limiting the generalisability of the study (Thomas 2011). However, Flyvbjerg (2006) argues that cases, such as the 12 PS events, can be examples to learn from. The learning can enable transferability of parts of the findings to other contexts with similar characteristics (Guba 1981). The PS events of this study contribute to the design of hospital work systems, which are socio-technical systems with a complex nature (Hignett et al. 2013). Thereby, other socio-technical-based contexts may have the same characteristics and can thereby draw from the PS framework of this study, e.g. service systems design.

6. Conclusion

The aim of this study was to develop a framework describing the process of how ergonomics knowledge is created in PS. Based on three different types of PS in three hospital design projects, we applied a knowledge creation perspective and the process mining method. The theoretical perspective and the method resulted in a new understanding of PS in the ergonomics field. The analysis of the PS events resulted in a framework revealing five activities and six sub-activities connected in overlaps and sequential relationships, constituting the knowledge creation process of PS. The most central activities were *sharing work experiences*, *experimenting*, *interacting with simulation medium* and *reflecting*. These activities led to the creation of ergonomics knowledge in the form of participants formulating joint design specifications with the aim of designing a future work system supporting both human well-being and overall system performance.

The framework reveals the hidden steps of the PS process. Understanding of these steps is central when ergonomists plan and facilitate PS aiming at the design of ergonomics work systems. Therefore, based on the developed framework, we have formulated four implications for practitioners to take into account when planning and facilitating PS:

- It is important to encourage simulation participants to explain their own work to foster externalisation of their work experiences. Sharing of work experiences leads to engagement of participants in experiments addressing how to design an ergonomic work system.

- PS should be planned to include experiments in the form of both scenario acting and what-if discussions. Scenario acting often leads to what-if discussions; therefore, both types of experiments are needed in the knowledge creation process.
- The simulation medium should be selected to support both types of experiments. In the acting of scenarios, the medium should provide the participants the opportunity for grasping and moving parts. In what-if discussions, the medium should provide the participants the opportunity for pointing at parts that are the focus of the discussion.
- It is important to introduce opportunities for participants to reflect on the ergonomics consequences of the experiments. Such reflections are an essential step towards the creation of ergonomics knowledge in the form of joint design specifications.

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Appendix A

The extended coding protocol applied to the video recordings of the 12 participatory simulation PS events is presented in Table A1.

Appendix B

In Table B1, the frequencies of connections in the form of sequential relationships between the 13 sub-activities are displayed. An example from the table is *what-if discussions* (the 4th column) led to *addressing ergonomics consequences* (the 11th row). The frequency of that connection was 6.57% of the total number of sequences. This was the most frequent sequential relationship identified between the sub-activities.

Appendix C

Table C1 shows the overlap of timestamps between the 13 sub-activities and thereby which sub-activities often took place at the same time. An example from the table is that the overlap between *pointing* (the 4th column and row) and *what-if discussions* (the 2nd column and row) constituted 11.19% of the total number of overlaps. This was the highest number of overlaps identified between the sub-activities.

Table A1. The coding protocol of the video recordings.

Main activities	Description of main activities	Sub-activities	Description of sub-activities
Sharing work experiences	Share work experiences or viewpoints based on professional background	*Explaining personal needs*	Explaining individual personal needs based on professional work experiences
		Explaining own work	Explaining own work in the current or future work system
		Including actors not present	Taking professions or other actors into account who are not related to the participant's profession and not present at the simulation
		Asking other participants	Asking about other participants' work and work experiences
Interacting with simulation medium	When the simulation medium is actively applied in discussions among the participants	*Pointing*	Pointing at the simulation medium, but not physically interacting
		Physically testing and interacting	Physically interacting with the simulation medium by grasping or moving parts
Experimenting	Test or discuss different design suggestions or scenarios	*Acting scenarios*	Acting scenarios either defined beforehand or developed continually during the simulation events
		What-if discussions	Discussions of future scenarios, often starting with 'what if ...'
Reflecting	Consider, assess and react to the insights on future ergonomics conditions obtained during experiments	*Addressing ergonomics consequences*	Addressing and assessing ergonomics consequences of the work system design
		What happened here	Wondering comments, often starting with 'what happened here ...?'
		Emotional reactions	Spontaneous emotional reactions related to the realised ergonomics consequences
Proposing new design	Jointly agree upon design changes of the work system	*Manipulation of simulation medium*	Introduction of design changes by manipulating the simulation medium
		Formulating joint design specifications	Jointly formulated design specifications in the form of either specific requirements or intangible focus points

Table B1. The sequential relationship between the 13 sub-activities, expressed as frequencies of the identified sequences. The frequencies are normalised in relation to the total number of sequences (4417) identified between all sub-activities. The direction of the sequential relationships is from the sub-activities listed in the columns to the sub-activities listed in the rows. The grey scale indicates where the highest frequency occurred.

	Simulation starts	Acting scenarios	What-if discussions	Physically testing and interacting	Pointing	Asking other participants	Explaining own work	Explaining personal needs	Including actors not present	Addressing ergonomics consequences	Emotional reactions	What happened here	Formulating joint design specifications	Manipulation of simulation medium	Simulation ends
Simulation starts	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acting scenarios	0.07	2.26	0.95	1.34	0.41	0.23	0.77	0.11	0.11	0.57	0.11	0.02	0.16	0.02	0.00
What-if discussions	0.18	1.13	3.74	1.54	2.26	0.52	3.26	0.45	0.93	5.14	0.54	0.11	1.22	0.25	0.00
Physically testing and interacting	0.00	2.42	1.56	3.42	1.38	0.29	1.25	0.14	0.16	1.20	0.18	0.07	0.25	0.16	0.00
Pointing	0.18	0.68	2.72	1.22	2.31	0.29	1.72	0.20	0.45	2.20	0.23	0.07	0.82	0.11	0.00
Asking other participants	0.00	0.50	0.72	0.45	0.34	0.11	0.82	0.20	0.23	0.68	0.16	0.00	0.16	0.00	0.00
Explaining own work	0.00	0.57	2.08	0.68	1.20	1.97	1.15	0.25	0.48	1.74	0.27	0.16	0.41	0.07	0.00
Explaining personal needs	0.00	0.02	0.52	0.02	0.16	0.27	0.29	0.05	0.09	0.25	0.02	0.00	0.07	0.00	0.00
Including actors not present	0.00	0.07	0.70	0.11	0.48	0.14	0.34	0.05	0.14	0.54	0.07	0.11	0.27	0.02	0.00
Addressing ergonomics consequences	0.02	0.70	6.57	1.29	2.51	0.45	1.81	0.36	0.41	1.70	0.43	0.25	0.70	0.14	0.00
Emotional reactions	0.00	0.09	0.72	0.27	0.18	0.07	0.23	0.05	0.09	0.48	0.05	0.05	0.05	0.00	0.00
What happened here	0.00	0.11	0.18	0.11	0.11	0.02	0.14	0.05	0.02	0.18	0.00	0.02	0.05	0.00	0.00
Formulating joint design specifications	0.00	0.05	0.75	0.14	0.48	0.02	0.41	0.05	0.20	1.36	0.07	0.07	0.23	0.05	0.00
Manipulation of simulation medium	0.00	0.02	0.20	0.07	0.16	0.00	0.02	0.02	0.02	0.23	0.07	0.02	0.02	0.00	0.00
Simulation ends	0.00	0.00	0.09	0.00	0.05	0.00	0.05	0.02	0.02	0.05	0.07	0.00	0.02	0.00	0.00

Table C1. The overlap of timestamps between the 13 sub-activities. The overlaps displayed are normalised in relation to the total number of overlaps (2288) between all of the sub-activities. The table can be read from the columns to the rows and from the rows to the columns. The grey scale indicates where the highest frequency of overlap occurred.

	Acting scenarios	What-if discussions	Physically testing and interacting	Pointing	Asking other participants	Explaining own work	Explaining personal needs	Including actors not present	Addressing ergonomics consequences	Emotional reaction	What happened here	Formulating joint design specifications	Manipulation of simulation medium
Acting scenarios	0.00	0.13	10.31	1.35	0.70	1.40	0.04	0.09	0.31	0.00	0.00	0.04	0.00
What-if discussions	0.13	0.00	4.20	11.19	0.83	1.97	0.52	0.87	1.09	0.04	0.00	0.26	0.09
Physically testing and interacting	10.31	4.20	0.00	0.04	0.44	0.92	0.09	0.04	0.87	0.04	0.00	0.09	0.74
Pointing	1.35	11.19	0.04	0.00	0.26	0.79	0.22	0.17	4.41	0.13	0.13	0.39	0.00
Asking other participants	0.70	0.83	0.44	0.26	0.00	0.39	0.00	0.00	0.35	0.04	0.13	0.00	0.00
Explaining own work	1.40	1.97	0.92	0.79	0.39	0.00	0.31	0.09	0.92	0.09	0.04	0.04	0.04
Explaining personal needs	0.04	0.52	0.09	0.22	0.00	0.31	0.00	0.00	0.35	0.39	0.00	0.00	0.00
Including actors not present	0.09	0.87	0.04	0.17	0.00	0.09	0.00	0.00	0.61	0.04	0.00	0.09	0.00
Addressing ergonomics consequences	0.31	1.09	0.87	4.41	0.35	0.92	0.35	0.61	0.00	0.17	0.09	0.35	0.17
Emotional reaction	0.00	0.04	0.04	0.13	0.04	0.09	0.39	0.04	0.17	0.00	0.00	0.00	0.04
What happened here	0.00	0.00	0.00	0.13	0.13	0.04	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Formulating joint design specifications	0.04	0.26	0.09	0.39	0.00	0.04	0.00	0.09	0.35	0.00	0.00	0.00	0.00
Manipulation of simulation medium	0.00	0.09	0.74	0.00	0.00	0.04	0.00	0.00	0.17	0.04	0.00	0.00	0.00

APPENDIX I: CONFERENCE PAPER 3

The role of knowledge objects in participatory ergonomics simulation

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Participatory ergonomics simulations, taking place in simulation labs, have the tendency to get detached from the surrounding design process, resulting in a knowledge gap. Few studies in the human factors and ergonomics field have applied knowledge management based object concepts in the study of knowledge generation and transfer over such gaps. This paper introduces the concept of *knowledge object* to identify the roles of objects in an exploratory case study of five participatory simulation activities. The simulations had the purpose of contributing to room design of a new Danish hospital. The analysis showed sequences and transitions of the knowledge objects revealing the process behind the knowledge interpretations and development of the future hospital rooms.

Practitioner Summary: When planning participatory simulation in a lab context, the ergonomist should consider the role of objects in generation of ergonomics knowledge and transfer of this knowledge to actors in the surrounding design process. Design actors receiving simulation documenting objects interpret and transform the represented knowledge according to their local context and experiences.

Keywords: Participatory Ergonomics, Simulation, Knowledge Objects, Architectural Design

1. Introduction

This paper presents an exploratory case study of participatory ergonomics simulation (Daniellou, 2007) applying full-scale mock-ups in design of a new Danish hospital. The simulations took place in a 'simulation lab' providing resources for building and exploring full-scale mock-ups. Within participatory design research, such labs have been defined as design labs (Binder and Brandt, 2008), interactive laboratories (Watkins, Myers, and Villasante, 2008), imaginative places (Brodersen, Dindler, and Iversen, 2008) etc. The lab provides the possibility for experimenting within a stable and controlled environment (Binder and Brandt, 2008; Watkins et al., 2008). This characteristic has the tendency to detach the participatory activities taking place within the lab from the surrounding and less controllable design process. This can be an advantage as defined by Brodersen et al. (2008) as elements of transcendence that "fuel the process of creating distance from current practice…" and "…open up the horizon of opportunity". However, the detachment of the lab might as well result in a gap between the lab and the surrounding design process. The gap needs to be overcome when sharing the knowledge generated within the lab.

Within the knowledge management field, objects in different kinds have been introduced in overcoming gaps or boundaries in knowledge sharing (e.g. Carlile, 2002; Ewenstein and Whyte, 2009; Gherardi and Nicolini, 2000). However, within the field of human factors and ergonomics, research of the knowledge sharing properties of object have been few. The characteristics of objects in direct interaction and communication between production workers and engineers are highlighted by Broberg et al. (2011). Objects, such as scale models and layout games, showed to support sharing of ergonomics knowledge during participatory ergonomics activities in a manufacturing redesign process. The characteristics of objects in communicating information over time and place are emphasized in the study of Conceição et al. (2012). Guidelines were designed to transfer ergonomics knowledge from offshore accommodation units to onshore design teams. Hall-Andersen and Broberg (2013) combine both the communication and transfer characteristics in analysing an engineering design process of a hospital sterile processing plant. Objects such as blueprint drawings and guidelines showed to assist knowledge sharing between ergonomists and engineers. This paper determines the objects of these three studies as *knowledge object*.

Knowledge objects are objects that support generation and/or transfer of ergonomics knowledge. They act as representations of ergonomics knowledge and their purpose is to overcome gaps between different design actors. This paper introduces the knowledge objects concept within an exploratory case study to investigate the role of objects applied in participatory simulation activities. This implies both the generation of ergonomics knowledge and transfer of this knowledge over the gap between the detached simulation lab and the surrounding design process.

1.1 Theoretical approach on knowledge objects

The knowledge object approach originates from the field of science and technology studies (STS). The STS argue for objects playing just as significant a role as human actors in sociotechnical processes, and often the role as mediators between different actors (Latour, 2005; Vinck, Jeantet, and Laureillard, 1996). The concepts of intermediary object (Callon, 1991; Vinck et al., 1996) and boundary objects (Carlile, 2002; Star and Griesemer, 1989) have been applied in the few studies of knowledge objects within human factors and ergonomics. Intermediary objects are "…objects that can be communicated and exchanged between design partners" (Vinck et al., 1996). Hall-Andersen & Broberg elaborate by highlighting that "an intermediary object is an object produced by a network of designers with the specific intent of transferring their knowledge and experience to downstream actors". In this paper designers are viewed as any actor involved in design activities. Boundary objects create a sheared understanding between actors from different social worlds (Star and Griesemer, 1989) and "…facilitates a process where individuals can jointly transform their knowledge" (Carlile, 2002). Hall-Andersen and Broberg (2013) add a term of boundary objects being "mediators in the direct communication between actors".

Drawing on the work of Nicolini et al. (2012) the concepts of intermediary objects and boundary objects can be seen as secondary objects of collaboration, thereby secondary knowledge objects. These concepts provide a significant value in the understanding of how knowledge is generated and transferred across different boundaries. However, they do not focus on the primary knowledge object, thereby why knowledge is generated and transferred. By introducing the concept of epistemic objects (Ewenstein and Whyte, 2007, 2009; Nicolini et al., 2012; Rheinberg, 1997) the 'why' and the motivation of the knowledge generation and transfer can be unfolded.

Epistemic objects "fuel cooperation and general mutuality and solidarity by triggering desire and attachment and creating mutual dependencies" (Nicolini et al., 2012). They are defined by their incompleteness (Cetina, 1996) and evolve when knew knowledge is discovered (Ewenstein and Whyte, 2007). An epistemic object is partially expressed in multiple instantiations, such as the secondary knowledge objects in the form of the intermediary objects and the boundary objects. Because of the fluidity of epistemic objects, they can be manipulated and evolved through these secondary knowledge objects (Ewenstein and Whyte, 2009; Whyte, Ewenstein, Hales, and Tidd, 2007). In contrast to the epistemic objects, Rheinberg (1997) defines the concept of technical objects. These are ready-to-hand, complete and unproblematic instruments (Ewenstein and Whyte, 2009), which are frozen in nature (Whyte et al., 2007). Epistemic objects are turned into technical objects when exploring and concretizing the unknown (Ewenstein and Whyte, 2009). The relations between the four knowledge objects concepts are presented in table 1.

Table 1. The relations between the four STS concepts of knowledge objects.

		Primary knowledge objects	
		Epistemic objects	Technical objects
Secondary knowledge objects	Intermediary objects	EI-objects: Represents a fraction of the not yet fully defined object under design. It transfers the represented knowledge to down steam actors. It is fluid in nature. Thereby, the receiving actors can interpret and manipulate the representation.	TI-objects: Represents a fully defined and unquestionable part of the object under design. It transfers the represented knowledge to down steam actors. It has a frozen nature. Thereby, it is stable to the receiving actors and not manipulated in any way.
	Boundary objects	EB-objects: Represents a fraction of the not yet fully defined object under design. It mediates direct communication between different actors. It is fluid in nature. Thereby, the actors can communicate and generate knowledge by manipulating and transforming the representation.	TB-objects: Represents a fully defined and unquestionable part of the object under design. It mediates direct communication between different actors. It has a frozen nature. Thereby, the participating actors do not manipulate it during the communication.

2. Method

This paper is based on an exploratory case study of participatory ergonomics simulation taking place within a regional simulation lab in Denmark. The lab was established for contributing to the design process of a new major hospital, a merger between two existing regional hospitals. The primary resources of the lab were full-scale mock-ups facilities. By applying movable chipboard walls, foam bricks and standard hospital furniture, the facilitators of the lab constructed design proposals for future hospital rooms. These mock-ups were staging the simulation events, with the purpose of testing and developing standard rooms to be repeated throughout the new hospital building design. The participants of the simulations were healthcare professionals from the existing hospitals, project employees and consultants. The participants adjusted the mock-ups during the simulations, leading to a redesign of the tested hospital room design. The case study investigated five simulation events in depth, presented in table 2.

Table 2. Overview of the five simulation events.

	Sim 1	Sim 2	Sim 3	Sim 4	Sim 5
Area of design	New beds ward reception area.	New beds ward corridor including a bed paternoster lift.	New outpatient examination room.	New depot for bed ward.	New cancer day treatment ward.
Partici-pants	4 secretaries, 2 charge nurses, 1 hospital management, 2 IT consultants, 2 facilitators, 1 project employee.	1 hospital porter, 1 technical employee, 2 project employees, 2 technical consultants, 2 facilitators.	4 secretaries, 2 charge nurses, 1 hospital management, 2 IT consultants, 2 facilitators, 1 project employee.	2 nurses, 2 project employee, 1 facilitator.	2 charge nurse, 1 nurse, 2 facilitators.
Simu-lation process	Participants were standing in the mock-up discussing future work scenarios, leading to adjustments of the mock-up.	Participants acted out different scenarios by manoeuvring a standard bed through the mock-up, leading to mock-up adjustments.	Participants were standing in the mock-up discussing future work scenarios, leading to adjustments of the mock-up.	Participants were acting out scenarios of work practices and at the same time furnishing the rooms according to the practices.	Participants were standing in the mock-up and acting out scenarios of work practices, leading to adjustments of the mock-up.

Data collection was based on observations of the five simulation events, which as well were video-recorded. After each simulation event a selection of participants were interviewed about their experience of the simulation. The selection of interviewees was based on the criteria of gaining a variety of different professions. Each interview was documented in a summary including transcriptions of the parts related to the aim of the study. Furthermore, the documents applied or created in relation to the simulation activities were collected. The different types of data was analysed with the theoretical approach of knowledge objects. The analysis had two foci; 1) identifying objects having a role in the knowledge generation during the simulation activities and in the knowledge transfer to the surrounding design process, and 2) investigating the roles of these objects from the perspective of the four STS concepts of knowledge objects.

3. Findings and discussion

The following sections present the identified knowledge objects of the five simulations. Furthermore, the roles of the identified knowledge objects are analysed and discussed by applying the STS knowledge objects concepts.

3.1 Architectural blueprints transfer knowledge to the lab

Before the simulation events the facilitators received a blueprint drawing of the initial design from the consulting architects, see figure 1 left for an example. The blueprints represented the design proposals to be tested and redesigned during the five simulation activities. The facilitators built the design proposals as mock-ups, which then represented the blueprints in 3D and full-scale. The facilitators strived to build the mock-ups as close to the blueprints as possible. However, they needed to adjust according to the mock-up materials available, e.g. the reception desk in simulation 1 was represented by a foam block instead of a real desk. Other parts of the blueprints were left out of the mock-ups because the facilitators considered them to be irrelevant, e.g. neighbouring rooms.

The blueprints can be seen as representations or ‘codifications’ (Gherardi and Nicolini, 2000) of the architects’ knowledge at that stage of the design process. This knowledge was transferred to the facilitators in the simulation lab, who translated the blueprint into mock-ups, limited by the material possibility. They interpreted the codified knowledge and translated it according to their local context and experience (Gherardi and Nicolini, 2000). Thereby, the blueprints had the characteristics of intermediary objects. At the time of transferral, the blueprints had a stable nature, representing well-defined designs of the future hospital rooms. However, the blueprints were sent to the simulation lab for exploration and testing. Thereby, the appropriateness or suitability of the designs was in question. This unfroze the blueprints, which became the trigger of the construction of the mock-ups. This change of status can be seen as the blueprints changing roles from technical object into representations the future desired rooms as epistemic objects. The transition is illustrated in figure 1 right.

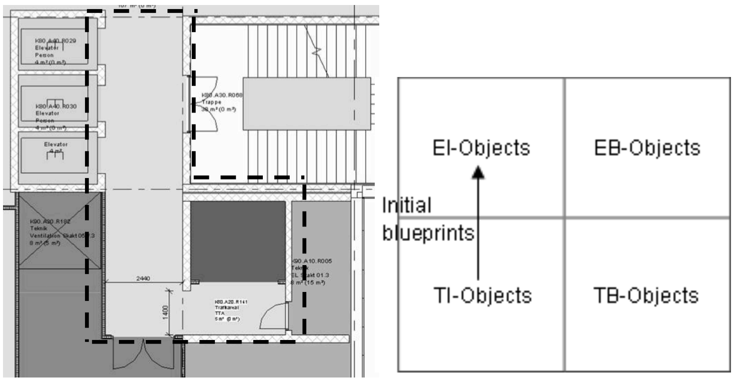


Figure 1: Left, blueprint of the bed ward corridor. The dashed lines show the part that was builded as full-scale mock-ups. Right, transition of the initial blueprints provided by the architects.

3.2 Full-scale mock-ups generate knowledge within the lab

In all the simulations the mock-ups, as representations of the future hospital rooms, were the primary desire and driver of the events. The participants explored the architectural design proposal by bodily experiencing the mock-ups. During discussion and acts of future user scenarios, the participants obtained an understanding of how the initial design would influence the work practices intended to take place in the room. This led to participants suggesting adjustments of the mock-ups and thereby adjusting the room design. The adjustments were easily implemented because of the flexibility of mock-ups in relation to the movable chipboard walls, foam bricks and standards hospital furniture. The adjustments resulted in an experimental approach, which is illustrated in the observed sequence of adjusting and reflecting from the second simulation event in figure 2 left.

The experimental approach made the participants reflect during the simulation events. The reflections led to generation of a common understanding of the ergonomics challenges, and how to cope with these through continually adjustments. This process continued until an acceptable design was agreed upon by the participants with different experience and background. Thereby, the mock-ups had the characteristics of boundary objects, by being mediators in the direct interaction between the different participants seen as belonging to different social worlds (Carlile, 2002; Star and Griesemer, 1989). The experimental approach was supported by the fluid nature of the mock-ups. The movable chipboard walls, foam bricks and standard hospital furniture made it easy for the participants to constantly transform the mock-ups according to the evolving common understanding. The participants were throughout the simulation trying to concretize and define the incomplete hospital room and the work practices taking place within this room. In that way, the mock-ups had the characteristics of being representing the desired future rooms as epistemic objects. Throughout the adjustments the lack of completeness decreases and the mock-ups started to be more frozen in nature in terms of being concretized. In so, the mock-ups turned towards technical objects. The transition is shown in figure 2 right.

Hospital porter:	(Pulls the extra-long hospital bed out of the paternoster lift by pulling the headboard. Starts turning the bed at the same time with the purpose of being prepared for driving down the corridor, when the bed is out of the paternoster. The space is limited and it seems like the bed is incapable of getting out.)
Project employee:	"Uhhhh"
Consultant:	"Take it easy, bear in mind it's the extra-long bed we are trying now." (She addresses the project employee.)
Hospital porter:	(Goes to the foot of the bed, which is half way out of the paternoster now, and pulls out sideways the foot end. Suddenly the bed's wheel collides with the foam brick representing a slide door of the paternoster lift. The foam brick is moved out of place and the foam wall is almost collapsing.)
Architect:	"A door just crashed" (Walks towards the foam brick)
Facilitator:	"But the difference was that because we made the corridor narrower?" (Points at the movable wall opposite the paternoster lift.)
Architect:	"Yes, I think so". (Putting the foam brick into place again.)

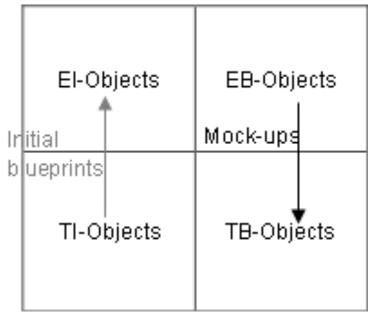


Figure 2: Left, experimentation of turning the hospital bed in different width of the corridor. Right, transition of the mock-ups during the simulation events.

3.3 Documents, lists and notes sustain and transfer generated knowledge out of the lab

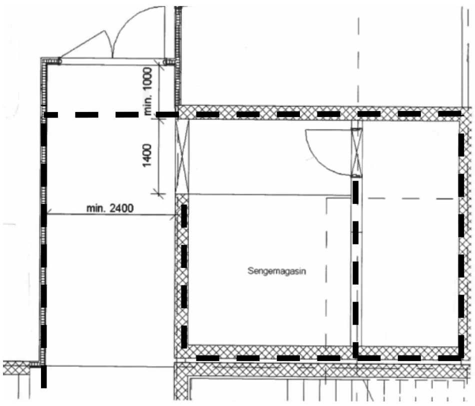
In all simulations, objects were produced during or directly after the events, with the purpose of documenting the generated ergonomics knowledge and design adjustments. Table 3 presents an overview of the produced object. These objects had the ability of sustaining the results and the generated knowledge of the simulation events. The sustained knowledge was highly influenced by the actors producing the objects. The facilitators and the project employee, producing the objects in simulation 1, 3, 4 and 5, had a high focus on the clinical and ergonomics conditions. This was reflected in the documents and sketches by including e.g. ergonomics considerations of the space around work stations. The participating architect producing the objects in simulation 2 had a high focus on the room dimensions. This was reflected in the notes by including e.g. minimum dimensions of the corridor for the bed to turn.

The produced objects were afterwards transferred from the simulation lab to the surrounding hospital design process. The purpose was to transfer the generated ergonomics knowledge to actors in the design process for integration in the hospital design. In simulation 1 the receiving architect interpreted the document and list, and then adjusted the original blueprint according to that interpretation. He interpreted a point of attention on discretion of patient information as mainly focused on the back-office reception area. Thereby, he integrated a glass wall and door for separating the reception desk and the back-office without blocking daylight. However, the discussion among the simulation participants had also concerned discretion in the reception desk area. The generated knowledge was thereby distorted in the transfer. In simulation 3, 4 and 5 the same kind of distortion was identified. In these simulations the introductions of new furniture and dimensions were not interpreted by the receiving architects in the same way as discussed by the simulation participants.

In simulation 2 the interpretation went more straightforward, because the architect in charge of integrating the simulation outcome participated in the simulation activity. He produced his own notes and transferred these directly to the surrounding design process. In this case however, the adjustments of the original blueprint implied moving a wall into a neighbouring ventilation room. This task started a negotiation process with the engineers in charge of the ventilation system. The original blueprint was the basis for the engineers verifying that the architect could move the wall according to the design adjustments created during the simulation. The transformed blueprint of simulation 2 is presented in figure 3 left.

Table 3. Overview of the produced objects for sustaining generated knowledge

	Sim 1		Sim 2	Sim 3	Sim 4	Sim 5
Objects produced	Descriptive document.	Adjusted furniture list	Design notes on post-it	2D sketch.	2D sketch.	Descriptive document
Producing actors	Facilitators	Project employee	Participating architect	Facilitators	Facilitator	Facilitators
Focus	Adjusted dimensions, ergonomics consideration and patient information discretion	Adjusted number of work stations and inclusion of new technology	Adjusted dimensions of the corridor	Adjusted arrangement of the interior to increase patient experience	Adjusted dimensions and interior to optimize work practices	Adjusted arrangement of the interior for ergonomic work stations
Time of production	Right after simulation	Right after simulation.	During simulation	Right after simulation	During simulation	Right after simulation
Way of transfer-ring	Through common database	Through space management software	Physically transferred to architectural office by the participating architect.	Through common database	Through common database	Through common database
Receiving actors	Architect in charge of bedward reception area. Not participating in simulation	Architect in charge of bedward reception. Not participating in simulation	Architect in charge of the bedward corridors and paternoster lifts. Participated in the simulation	Architect in charge of outpatient department. Not participating in simulation	Architect in charge of bedward depot. Not participating in simulation	Architect in charge of day treatment ward. Not participating in simulation



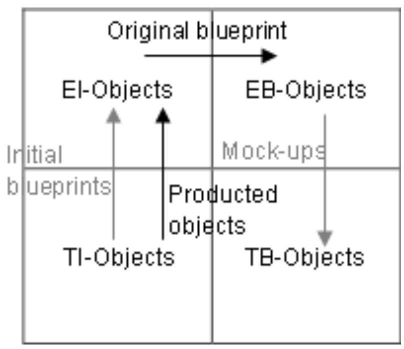


Figure 3: Left, adjusted blueprint of the corridor and paternoster lift. The dashed lines show the dimensions of the initial blueprint. Right, transition of the produced objects and the original blueprints.

The produced objects showed the abilities of freezing the generated knowledge by codifying the producers' view on the simulation outcomes (Gherardi and Nicolini, 2000). This codified knowledge was transferred to architects in the design process, who acted as downstream actors (Hall-Andersen and Broberg, 2013). Thereby, the produced objects had the intermediary objects characteristics of transferring knowledge. The knowledge transferred was stable design changes decided upon, relating to the characteristics of technical objects. However in simulation 1, 3, 4, and 5, interpretation of the transferred knowledge showed to have a significant impact on the transformation of the original blueprints. The architects interpreted and translated the objects according to the architects' own degree of freedom in the local but complex design context:

"If I get information, which doesn't fit the building shape and format, I need to analyse it… I analyse what I think their (the facilitators of the simulation) intensions are and then try to press it into the squire I have available. I analyse it with my experience as foundation and the knowledge of the department I have after all." – Architects in charge of bed ward, including reception and depot

The translation opened up the frozen nature of the transferred intermediary objects, because the architects considered the codified knowledge to lack the constraining conditions of their local context. This lack turned the stable transferred objects into a representation of fluid epistemic objects. The transition is illustrated in figure 3 right.

In simulation 2 the transferred intermediary object, in the form of the design notes, was held relative stable and remained to be a technical object. Instead the original blueprint played a more significant role. The original blueprint was unfrozen in the action of the architect sending it to the simulation lab for testing and development. In this action the blueprint transferred knowledge from the architect to the simulation facilitators as an intermediary object. In the discussion between the architect and the ventilation engineers taking place after the simulation, the original blueprint remained fluid as an epistemic object. But it was also supporting the communication between the architect and engineers at the spot of the negotiation of moving the corridor wall. The negotiation resulted in the architect and engineer reaching a common acceptable solution, relating the blueprint to the characteristics of boundary objects. Thereby, the blueprint was in both situations a representation of the future design as the epistemic object, but changed the secondary knowledge object role from being an intermediary object to being a boundary object. The transition is shown in figure 3 right.

4. Concluding remarks

The exploratory case study of five participatory ergonomics simulations showed that knowledge objects support knowledge generation and transfer in participatory ergonomics simulation taking place within a simulation lab context. The STS based knowledge objects approach enabled identifying and analysing objects' roles in the ergonomics knowledge generation and transfer. The knowledge objects identified were the blueprints of the initial room design, the mock-ups and the produced objects sustaining the outcome of the simulations. All these knowledge objects were in different ways representing the objects of desire; the future hospital rooms. When the rooms were under development in the simulation lab and in the surrounding design process, the room design could be considered to have a lack of completeness. This lack of completeness showed to be the driver of the knowledge generation and transfer, leading to the knowledge objects having characteristics of epistemic objects. During all the simulations, the room designs were occasionally frozen, leading to a stable representation of the desired rooms and thereby having the characteristics of being technical objects.

The representing objects were per se not the direct reason for the knowledge generation and transfer, thereby not the primary knowledge objects. However, their roles as secondary knowledge objects in the form of intermediary objects and boundary objects cannot be neglected. They highlight how the epistemic objects of future hospital rooms develop. Transformation of the intermediary objects and boundary objects resulted in transitions between fluid design suggestions and relative frozen suggestions and vis-à-vis.

The identified knowledge objects occurred in sequences revealing the process behind the development of the future hospital rooms. The sequences included actors generating, interpreting and translating the objects according to their different experiences and local contexts. Thereby, the generated and transferred knowledge was constantly adjusted. Especially the interpretations of the objects produced during or after the simulations resulted in knowledge distortion when transferred over the gap between the simulation lab and the surrounding design process.

Suggestion of implications for practitioners:

- When planning participatory ergonomics simulation in simulation lab contexts, ergonomists should consider the primary knowledge object, which should motivate the process of ergonomics knowledge generation and transfer.
- Furthermore, secondary knowledge objects representing and transforming the primary knowledge object should be considered in relation to their ability of assisting knowledge generation and transfer.
- Secondary knowledge objects transferred between different actors are interpreted and translated according to the receivers' context and experience. Thereby, the number of different actors involved in the production and interpretation of the objects should be at a minimum for decreasing knowledge distortion. Thereby, direct involvement of the designers in the simulation activities is preferable.

Acknowledgement

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APPENDIX J: JOURNAL PAPER 3

Submitted and currently under review in *Human Factors and Ergonomics in Manufacturing and Service Industries*

Ergonomics knowledge transfer from participatory simulation and integration into hospital design

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Abstract:
Existing research on participatory simulation (PS) has mainly focused on the execution. The subsequent transfer of the simulation outcomes and integration into the workplace design have gained low attention, even though this process is crucial for having an actual design impact. This study investigates the mechanisms behind transfer of ergonomics knowledge from PS events and integration into hospital design. Theoretical concepts of knowledge transfer and integration guided a case study of six PS events, which contributed to the design of a major hospital. The ergonomics knowledge transfer and integration showed to be an intertwined process of intermediary actors, intermediary objects, object producers, knowledge receivers, and two influencing factors as design constraints. We argue that when planning PS events, the ergonomist has to take into account this intertwined process of knowledge transfer and integration to ensure an impact on the final hospital design.

Key words: Participatory ergonomics, Participatory simulation, Knowledge transfer, Knowledge integration, Hospital design

1. Introduction

Design of new hospitals includes not only the design of the physical building, but also new ways of organizing work, new healthcare technologies, new treatments, and new work practices. An approach for integrating ergonomics in workplace design is participatory ergonomics, which involves the future workers in the design process (e.g. Garrigou et al., 1995; Seim and Broberg, 2010). Participatory simulation (PS) is a participatory ergonomics method in which future workers participate in simulations of their future workplace and work practices. PS has the following aims: to innovate the workplace design (Broberg & Edwards, 2012), to enable evaluation of future ergonomics conditions (Andersen & Broberg, 2015), and to adjust the design to improve the future ergonomics (Daniellou, 2007).

The process of PS can be conceptualized as combining the experiences and know-how of the different participants, thereby creating new ergonomics knowledge (Nonaka, 1994), e.g. becoming aware of ergonomics challenges or formulating design criteria and adjustments to comply with those challenges. The knowledge is "ergonomics" in the sense that it has a focus on improving the future workers' well-being and the overall performance. Subsequent to the PS, the created ergonomics knowledge has to be *transferred* and *integrated* into the hospital design. This can be conceptualized as a two-step process. The first step is the transfer of the ergonomics knowledge from the PS events into the overall hospital design process. The second step is to integrate the ergonomics knowledge into the hospital design, thereby making the knowledge from the PS events have a design impact.

Within the knowledge management field, knowledge transfer and integration are closely linked. Knowledge transfer may be defined as "the conveyance of knowledge from one place, person or ownership to another" (Liyanage, Elhag, Ballal, & Li, 2009). Integration may be defined as happening "when knowledge that originates in one context or location is used and applied in another" (Kumar & Ganesh, 2009). Within the human factors and ergonomics field, ergonomics knowledge transfer and integration have mainly been studied from the perspective of transferring knowledge from ergonomics researchers to practitioners (Antle et al., 2011; Carayon, 2010; Guzman, Yassi, Baril, & Loisel, 2008; Neumann, Dixon, & Ekman, 2012; Seim, Broberg, & Andersen, 2014; Seim & Broberg, 2010). The knowledge transfer and integration are considered to be crucial for the success of ergonomics interventions. Other studies have investigated the transfer of ergonomics knowledge to engineering design in the form of ergonomics guidelines or other standards (Broberg, 2007; Campbell, 1996; Conceição, Silva, Broberg, & Duarte, 2012; Hignett & Lu, 2009; Kim, 2010; Skepper, Straker, & Pollock, 2000; Wulff, Westgaard, & Rasmussen, 1999). The focus of these studies has been on the configuration of the guidelines and the application by engineers. Furthermore, the transfer of ergonomics knowledge from ergonomists to engineering designers has also been analyzed as a key step in ergonomics integration (Hall-Andersen & Broberg, 2013).

When examining the studies of PS or other participatory ergonomics activities, the research focus is mainly on the execution of the activities and not on the subsequent knowledge transfer and integration (e.g. Hallbeck et al., 2010; Seim & Broberg, 2010; Steinfeld, 2004; Sundin, Christmansson, & Larsson, 2004). Yet the knowledge transfer and integration is a crucial step for the participatory activities to have an impact on the final workplace design.

Broberg et al. (2011) address the process of transferring the outcome of participatory ergonomics events into a parallel engineering design process. The transfer is reflected upon as a circulation of objects, such as layout games and scale models, which materialize the outcome of the participatory events. However, the process of ergonomics knowledge transfer and integration must be more thoroughly analyzed in order to understand the mechanisms behind it. *Therefore, the aim of this study is to investigate the mechanisms behind ergonomics knowledge transfer from PS events and integration into hospital design.* A better understanding of the mechanisms will provide new insights for ergonomists to take into account when planning and facilitating PS events, with the purpose of promoting the subsequent knowledge transfer and integration.

1.1 Concepts of knowledge transfer and integration

Knowledge transfer and integration may be defined as having two main approaches. The first approach is related to the process of communicating and viewing knowledge as a piece of information disseminated from a sender to a receiver (Gupta & Govindarajan, 2000; Kumar & Ganesh, 2009; Yakhlef, 2007). In this approach the success of knowledge transfer is when the receiving unit assimilates the knowledge as the process of knowledge integration (Liyanage et al., 2009). The second approach views the process of knowledge transfer and integration in light of being situated within and depending on contexts. In the transfer, the knowledge has to be contextualized to be valuable in the new setting. This process is often defined as translation, transformation or interpretation (Liyanage et al., 2009; Yakhlef, 2007). This means that the receiving actors interpret and translate the knowledge according to their own context and experiences (Gherardi & Nicolini, 2000). Furthermore, the actors apply the translation in their work as the process of knowledge integration. Existing studies of ergonomics guidelines have a high focus on the communication of pieces of ergonomics information (Kim, 2010; Skepper et al., 2000; Wulff et al., 1999), the first knowledge transfer and integration approach. To contribute a new perspective on ergonomics knowledge transfer and integration, we applied the second approach in this study.

The second approach to knowledge transfer and integration highlights the role of *intermediaries*, those having the ability to circulate among different settings and actors (Gherardi & Nicolini, 2000). The two intermediaries in this study are *actors* and *objects*. Actors can carry embedded knowledge from one setting into another setting, and translate this according to the new context (Boh, 2007; Kumar & Ganesh, 2009). So actors can have the role as boundary spanners among several settings (Wenger, 2000). Objects have the ability to codify and represent the knowledge of the producers and can be exchanged between actors (Boujut & Blanco, 2003; Vinck, Jeantet, & Laureillard, 1996). Objects can be open or closed. Open objects represent knowledge open for interpretation and exploration. Closed objects represent knowledge which is supposed to be ready to handle and is unquestionable (Vinck et al., 1996; Whyte, Ewenstein, Hales, & Tidd, 2007).

1.2 The study focus

The investigation of transfer and integration of ergonomics knowledge from PS events into hospital design is approached by applying the concept of intermediaries as an analytical frame. The empirical foundation is six PS events aimed at contributing to the design of a new major

Danish hospital. The study is conducted as a case study and guided by the following three research questions:

- How are intermediaries enabling ergonomics knowledge transfer?
- What parts of the transferred ergonomics knowledge are integrated?
- What are the main factors influencing the ergonomics knowledge integration?

Within this case study, ergonomics *knowledge transfer* is defined as the process of sending or bringing knowledge (created during the six PS events) to architects and engineers engaged in the hospital design process. *Knowledge integration* is defined as architects and engineers interpreting, translating and applying the received ergonomics knowledge into the hospital design.

In the following sections we provide a case description and methodological reasoning behind data collection and analysis. The results are presented according to the three research questions, leading to a discussion relating the results to the theoretical concepts on knowledge transfer and integration. The paper ends with concluding remarks and four implications for practitioners.

2. Method

The background of the study was a current renewal process of the Danish public hospitals. The purpose of the renewal was to renovate existing hospitals and design new hospitals to improve the efficiency and quality of Danish healthcare. To assist the design process, the Danish Regional Counsels funded several innovation centers, with the aim of involving healthcare professionals from the existing hospitals in the design of new hospitals. The methods applied in the centers can be seen as PS, where the healthcare professionals participated in simulations of the future hospital workplaces. This study focuses on one of the innovation centers, which was related to a building project of a major new hospital, merging two existing hospitals. We approached six PS events taking place in the innovation center as a case study. In the following sections we present the innovation center, the case study approach of the six PS events, and the methods for data collection and analysis.

2.1 The innovation center

The innovation center was located in a hall at the construction site of the new hospital. The hall provided the necessary space for building full-scale mock-ups of the future hospital rooms. The mock-ups consisted of movable chipboard walls, foam bricks and standard hospital furniture, as illustrated in Figure 1. In cases where the project owner or the consulting architects had doubts about the appropriateness of a room design, the room was built as a mock-up and tested through PS by involving healthcare professionals from the merging hospitals. The PS was initiated to ensure that existing ergonomics knowledge of the healthcare professionals was communicated to the architects and engineers designing the new hospital. During the PS, healthcare professionals created new ergonomics knowledge by discussing and combining their different experiences. This often led to adjustments of the mock-ups, thereby the room was redesigned during the simulations. The created knowledge was communicated to the architects and engineers in the process of transferring the knowledge from the innovation centers to the hospital design offices for the purpose of integrating this into the hospital design.

Figure 1: The full-scale mock-ups applied in the PS session in the innovation center.

In addition to healthcare professionals, some of the PS events also involved staff from the project owner department, and engineers and architects from the consulting consortium. The consortium consisted of two engineering companies and two architectural companies collaborating in designing the new hospital. The innovation center and the PS events were facilitated by two project employees from the project owner organization - one employee with a clinical background and one employee with a background in occupational health and safety (OHS). At the time of this study, the hospital design process was approaching the detailed design stage, focusing on room dimensioning and layout.

A typical PS event in the innovation center started with an introductory meeting during which the center employees presented the room to be tested by showing the architectural blueprints of the room. The presentation led to discussions among the different participants, with a focus on the possible ergonomics challenges, e.g. possible critical work postures or conditions influencing the quality of treatment. The discussed challenges were the foundation for the following PS, which took place in a full-scale mock-up of the specific room. The mock-up was constructed beforehand by the center employees and in accordance with the architectural blueprints. During the simulation, the participants acted out and discussed future work scenarios to explore the ergonomics challenges, e.g. simulating the work postures of orderlies handling beds within a corridor. During the PS event, the participants adjusted the mock-up by moving the walls and furniture to improve the ergonomics conditions of the room. After the PS event, the identified ergonomics challenges and the design adjustments were documented with the purpose of being communicated to the architects and engineers in charge of designing the particular room. The intention was for the architect to integrate this ergonomics knowledge into the room design.

2.2 The case study

This study focuses on six PS events that took place in the innovation center. We approached the six PS events as a case study and investigated the ergonomics knowledge transfer and integration in relation to these six events. The six PS events are presented in Table 1, and were framed as six embedded units of analysis in the overall case of the innovation center (Thomas, 2011). The PS events were chosen based on the following two criteria: first, as simulations of key somatic rooms, that is rooms being repeated extensively throughout the future somatic hospital; second, as simulations of rooms intended to be used by mainly healthcare professionals, such as physicians, nurses, secretaries or orderlies. The criteria had the intention of supporting the comparison of the PS events.

	PS Event 1 1.5 hours	PS Event 2 1 hour	PS Event 3 1.5 hours	PS Event 4 1 hour	PS Event 5 1 hour	PS Event 6 1 hour
Area of design	New bed ward corridor, including a bed paternoster lift	New bed ward reception area	New depot for bed ward	New outpatient examination room	New, small, cancer day-treatment room	New, large, cancer day-treatment room
Participants	1 orderly, 1 technical employee, 2 project employees, 2 technical consultants, 1 architect, 1 engineer, 2 center employees	4 secretaries, 2 charge nurses, 1 hospital management staff member, 2 IT consultants, 1 project employee, 2 center employees	1 nurse, 2 head nurses, 2 project employees, 1 center employee	4 secretaries, 2 charge nurses, 1 hospital management staff member, 2 IT consultants, 1 project employee, 2 center employees	2 charge nurses, 1 nurse, 2 center employees	2 charge nurses, 1 nurse, 2 center employees
PS process	Participants acted out scenarios by maneuvering a standard bed through the mock-up, leading to mock-up adjustments.	Participants stood in the mock-up discussing future work scenarios, leading to adjustments of the mock-up.	Participants acted out scenarios of work practices and at the same time furnished the room according to the work.	Participants stood in the mock-up discussing future work scenarios, leading to adjustments of the mock-ups.	Participants stood in the mock-ups and acted out scenarios of work practices, leading to adjustments of interior design.	Participants stood in the mock-ups and acted out scenarios of work practices, leading to adjustments of interior design.

Table 1: The six PS events

2.3 Data collection and analysis

We collected different types of data with the purpose of conducting triangulation (Silverman, 1993) through the analysis, which was led by the three research questions.

2.2.1 Data collection and analysis of ergonomics knowledge transfer

We defined ergonomics knowledge transfer to be the process of sending or bringing knowledge (created during the six PS events) to architects and engineers within the hospital design process. To investigate the transfer, we focused on the creation of intermediary actors and intermediary objects, and the transfer of those from the innovation center to the design office, as illustrated in Figure 2. The collected data, in the form of observations, interviews and documents, are presented in Table 2. The observations were guided by an observation guide (Cresswell, 2013) focusing on the knowledge created and the transferring initiative of the PS events. The interviews were conducted with PS participants selected on the criteria of maximum variation (Flyvbjerg, 2006), that is, representing a variety of professions. The interviews were semi-structured (Kvale, 1996) and based on an interview guide focusing on the participants' perceptions of what ergonomics knowledge was created. The collected documents were selected based on having a possible role in knowledge transfer.

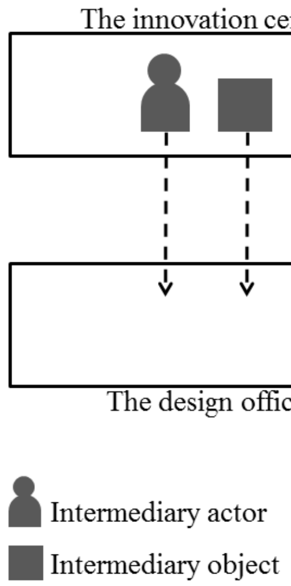

Figure 2: Focus of the first analysis

	PS Event 1 Bed ward corridor	PS Event 2 Reception area	PS Event 3 Depot	PS Event 4 Examination room	PS Event 5 Small treatment room	PS Event 6 Large treatment room
Observations	Observations of all the PS events					
Interviewees	- 1 hospital orderly from surgery hall - 1 architect from the design office - 1 technical consultant - 1 engineer from project management	-1 charge medical secretary from the medical department -1 IT consultant	-1 head nurse from oncology -1 project employee focusing on logistics -1 project employee focusing on space documentation	-1 staff member of the hospital management board -2 charge nurses from the medical department	-1 head nurse from hematology	-1 nurse from oncology
Documents collected	- Design notes taken by the architect	-Redesign description	-Sketch of redesigned room	-Sketch of redesigned room	-Redesign description	-Redesign description

Table 2: Collected data

The data were analyzed by applying the concepts of intermediaries as a theoretical frame (Miles & Huberman, 1994). The analysis followed three steps. First, coding of the data to identify intermediary actors or objects possibly involved in ergonomics knowledge transfer. Second, examining the coded data pieces of intermediary actors to analyze how their involvement possibly enabled knowledge transfer. This included analysis of their role of linking the PS events and the design process. Third, examining the coded data pieces of intermediary objects to analyze how they possibly enabled knowledge transfer. This included analysis of the created ergonomics knowledge of the events, the representation of this knowledge in the identified intermediary objects, and the transfer of these objects.

2.2.2 Data collection and analysis of ergonomics knowledge integration

We defined ergonomics knowledge integration as the process of architects and engineers interpreting, translating and applying received knowledge in the hospital design. By application, we refer to the process of architects or engineers making changes to design documents in accordance with the transferred knowledge. We expected that the transferred knowledge in this case was integrated through changes in the architectural blueprints, seen as design documents. So to analyze the integrated knowledge, we identified the changes in the blueprints by comparing the version of the blueprints before the PS events, the knowledge transferred by the intermediary objects and intermediary actors, and the changed architectural blueprints after the PS events, as illustrated in Figure 3. This enabled us to identify integrated and non-integrated parts.

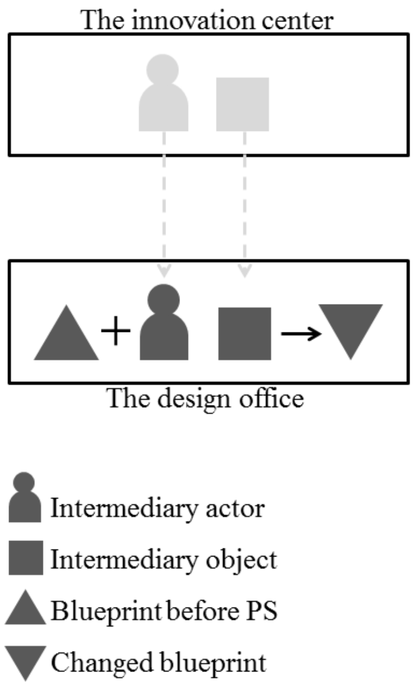

Figure 3: Focus of the second analysis

2.2.3 Data collection and analysis of factors influencing integration

To identify factors influencing the integration of ergonomics knowledge, we expanded the focus to the overall hospital design project, seen as the context providing the influencing factors as illustrated in Figure 4. We interviewed key actors of the hospital design project, as presented in Table 3. They were selected on the basis of fulfilling one of the following criteria: being project owner representatives, being actors receiving and applying knowledge from PS events, or being representatives from the consortium. The interviews were semi-structured (Kvale, 1996) and focused on factors influencing integration of ergonomics knowledge from PS events. The interview parts essential to the research question were transcribed and coded to identify challenges or conditions influencing the ergonomics knowledge integration. The factors which were most widely addressed across the interviewees, or which had a close link to the six PS events, were identified.

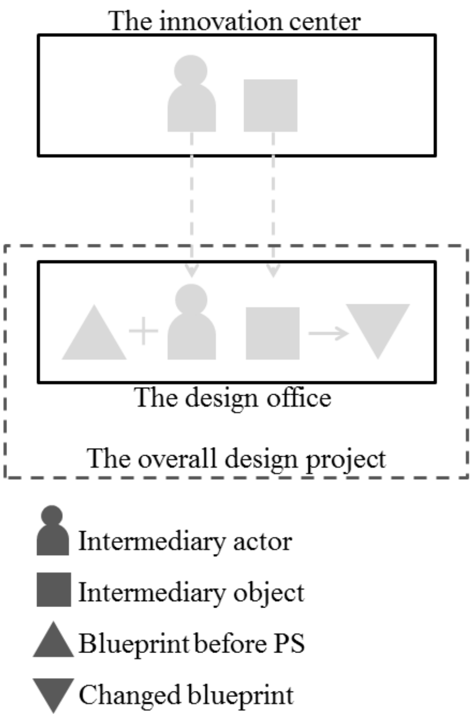

Figure 4: Focus of the third analysis

	Project owner representatives	Actors receiving and applying knowledge from PS events	Representatives from the consortium
Interviewees	- 1 project manager - 2 center employees	- 1 architect participating in PS Event 1 and integration of knowledge from PS Event 1 - 1 architect involved in integration of knowledge from PS Events 2 and 3	-1 architect involved in the management of the received intermediary objects -1 managing architect -1 engineer managing construction -1 project managing engineer -1 OHS consultant responsible for compliance with ergonomics legislation

Table 3: Interviewed key actors of the design project.

3. Results

In the following sections the results will be presented in accordance with the three research questions.

3.1 Intermediaries enabling ergonomics knowledge transfer

The results of the first analysis are presented in Table 4. The table first presents the ergonomics knowledge created in the form of identified ergonomics challenges and mock-up adjustments. Then the table presents the identified intermediary actors and intermediary objects, those who possibly transferred the created knowledge. The identified intermediary actors and intermediary objects are elaborated upon in the subsequent sections.

		PS Event 1, Bed ward corridor	PS Event 2, Reception area	PS Event 3, Depot	PS Event 4, Examination room	PS Event 5, Small treatment room	PS Event 6, Large treatment room
Created ergonomics knowledge	Ergonomics challenges	-Work posture of the orderly -Safety for technical staff	-Work posture when applying screens -Space in back office -Pressure of handling patient info. discreetly	-Work posture when collecting assistive devices -Inefficient work procedure in the room -Stock management of utensils	-Space behind workstation -Sufficient computer screens -Handling of separation wall -Having the needed tools	-Work posture around beds -Work posture at fixed cabinets -Handling of beds in emergencies -Oxygen access -Pressure of hand-ling patient info.	-Limited view of the beds from the nurses workstation -Handling of beds in emergencies -Pressure of handling patient info. discreetly -Work posture around beds
	Mock-up adjustments	-Adjustment of the corridor dimensions for improving work posture	-Reducing number of workstations to improve work posture when applying screens -Increasing back office area	-Cabinets for storage space -Larger assistive devices under shelves for improving work posture -Excluding separation wall, including printer in depot for work procedures -Reducing number of workstations	-New position of the workstation -Introduction of a third screen -Changed position of separation wall -Portable cabinets for external tool collection	-Chair instead of a bed increases space for work posture and emergencies -Portable cabinet instead of fixed improves work posture -Position of screen for discretion	-New position of workstation to increase overview -Position of screen for discretion -Replacing chair with bed to increase area for work and improve work posture and emergency procedures
Inter-mediary Actors		-Architect -Project engineer	No intermediary actors identified				
Intermediary Objects	Objects	-Personal notes	-Descriptive document	-Hand-drawn 2D sketch	-Hand-drawn 2D sketch	-Descriptive document	-Descriptive document
	Represented knowledge	-Minimum dimensions of corridor	-New dimensions of back office -New number of workstations -Point of attention on patient data discretion	-Introduction of cabinets -Introduction of assistive devices under shelves -New placement of printer within the depot, excluding the wall	-New position of workstation -Introduction of a third screen -New position of separation wall -Introduction of portable cabinets	-Introduction of chair -Introduction of cabinet -Point of attention on access to oxygen	-New position of workstation -Introduction of chairs replacing bed -Point of attention on access to oxygen
	Non-represented knowledge	-Safety issues for the technical staff	-Position of the workstation	-Explanation of the position of printer	-Explanation of the new workstation position	-New position of the screen	-New position of the screen

Table 4: The created ergonomics knowledge and the identified possible intermediaries.

3.1.1 Intermediary actors

The intermediary actors identified were the architect and project engineer in PS Event 1. The other PS events did not include actors with intermediary characteristics. The architect and engineer both participated in PS Event 1 and had a role in the hospital design process; though they proved to have different views on the ergonomics knowledge outcome of the PS event. The architect describes the ergonomics knowledge, which he obtained during the PS event, as an awareness of how adjustments of the corridor dimensions could improve the work posture of the orderlies handling beds in the corridor. He describes the awareness:

"When the orderly rotated the bed at the most narrow area [of the corridor], he got a twist in his back and arms. The flow of beds will be approximately 50 per day. This means that he is going to make that movement 50 times a day… The mock-ups made me ascertain that in the worst case scenario of rotating the bed, the wall to the ventilation room had to be moved one meter."

The architect explained that he was going to apply the knowledge of the one-meter corridor adjustment by changing the architectural blueprints upon returning to the design office. The engineer described the ergonomics knowledge she obtained in the same way as the architect, but she indicated another intended application of the knowledge:

"The testing [of the mock-ups] in the innovation center will contribute to fine-tuning the requirements specification."

In this way, the engineer was not going to apply the one-meter corridor adjustments by changing any blueprints. Instead, she described the contribution of the knowledge in relation to her project management position, which included coordination of the specification requirements. The architect and the engineer proved to have different integration intentions - one making very specific blueprint changes and one having a more general application on a managerial level.

3.1.2 Intermediary objects

The intermediary objects identified within the six PS events included three different types: personal notes, descriptive documents and hand-drawn 2D sketches. The three types of objects represented the ergonomics knowledge in different ways, also presented in Table 4. The personal notes, taken by the participating architects in PS Event 1, mainly focused on the corridor dimensions. The descriptive documents and the hand-drawn 2D sketches were produced by the facilitators as a summary of the overall simulation outcome. The descriptive documents included several focus points identified during the simulation. The hand-drawn 2D sketches showed the final stage of the mock-up after the adjustments introduced during the simulation. See Figure 5 for an example. However, the intermediary objects did not represent all parts of the created ergonomics knowledge. Some parts were not included, as shown in Table 4 as non-represented knowledge.

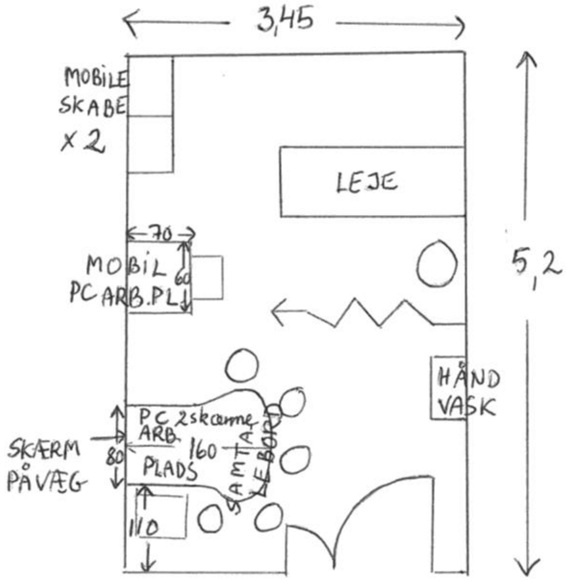

Figure 5: Hand-drawn 2D sketch representing the final stage of the examination room from PS Event 4.

The intermediary objects were all transferred to the hospital design process. The architect of PS Event 1 physically transported his personal notes to the architectural office. The descriptive documents and hand-drawn 2D sketches were transferred to the design office by being uploaded to a web-based platform, functioning as an interface between the project owners and the consortium. The platform enabled the architects and engineers to download the descriptive documents and hand-drawn 2D sketches when needed.

3.2 Integration of ergonomics knowledge

By comparing the blueprints before the PS events, the intermediary objects, and the changed blueprints after the PS events, we identified integration and non-integration as presented in Table 5.

	PS Event 1, Bed ward corridor	PS Event 2, Reception area	PS Event 3, Depot	PS Event 4, Examination room	PS Event 5, Small treatment room	PS Event 6, Large treatment room
Integration	-Indication of minimum dimensions of the corridor -Wall is moved 1 meter	-New dimensions of the back office area -Reduction of workstations from two to one	-Space under shelves for larger assistive devices is added	-New position of separation wall -Two portable cabinets are added -Third screen is added	-Replacement of bed with chair -One portable cabinet is added -Possibility for oxygen access	-Replacement of bed with chair
Non-integration	-	-Considerations on discretion of patient information in reception area	-New position of printer -Removing wall of printer niche -Reduction of number of workstations -Addition of cabinets	-New position of workstation	-	-New position of workstation

Table 5: Ergonomics knowledge integration and non-integration.

3.3 Main factors influencing ergonomics knowledge integration

Not all parts of the transferred knowledge were integrated. In the analysis of the hospital design project, we identified two main factors influencing the integration.

3.3.1 Building dimensions were already-set

In the hospital design project, the outer walls and bearing walls were defined during the early phases as a part of the architectural competition. This meant that in the detailed design phase, when the six PS events took place, the building dimensions were already-set. But in some situations, the received ergonomics knowledge from the PS events showed not to fit the building dimensions. An example of this was the knowledge transferred from PS Event 2 of the reception area. During the simulation, the participants decided to increase the depth of the back office without decreasing the front office respectively. An illustration of the room is presented in Figure 6. However, the new dimensions made the total depth of the two rooms exceed the depth of the building. But this was not realized during the simulation, and the increased depth was decided and transferred to the designers through a descriptive document.

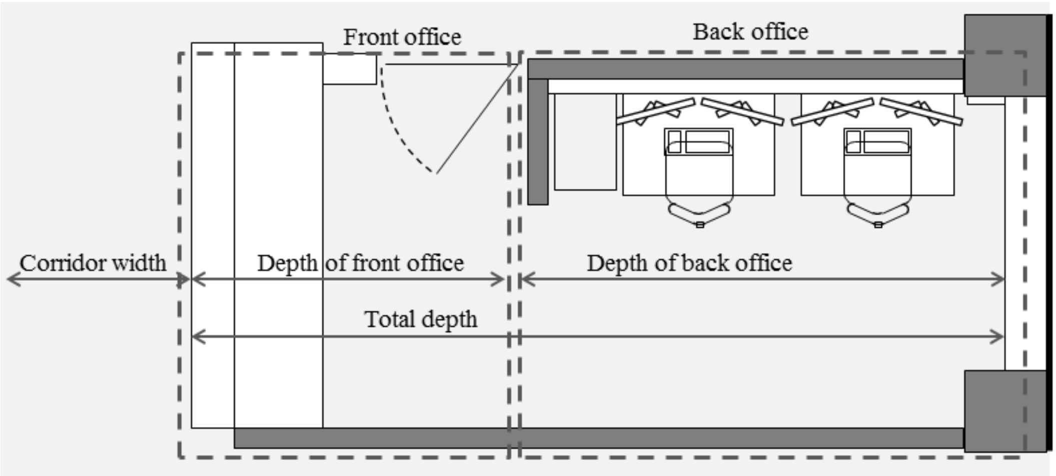

Figure 6: The depth of the back office and the front office.

In the integration situation, the architect could decrease the width of the corridor and provide space for integrating the new total room depth after all. But the possibility of decreasing the width of a several meter-long corridor was emphasized as a rare case by the architect in charge of the integration of knowledge from PS Event 2. He explained his usual strategy in cases in which he would receive ergonomics knowledge which could not be directly integrated in the already-set building dimensions.

"If I get information which doesn't fit the building shape and format, I need to analyze it… I analyze what I think their [the facilitators of the simulation] intentions are and then try to press it into the square I have available. I analyze it with my experience as the foundation and the knowledge of the department I have after all."

However from the project owner's point of view, the building dimensions seemed not to be as set. One of the center employees described the project owner's expectation as:

"Sometimes it is hard to get the architects to see the room's function. We had never imagined that it should be the physical frame that decided the function. It's now we have the chance to let the function decide the physical frame."

The project owners worked with the function as the determining factor during the PS events, and the designers worked with the building dimensions as the determining factor during the knowledge integration. This difference was recognized by several of the interviewed architects and engineers, who defined the situation as the consortium and the project owner approaching the hospital design process in opposite ways.

3.3.2 Rooms were highly interdependent

The rooms of the hospital were interdependent in two ways - first due to a fixed number of total square meters for each floor and second due to bearing walls, stairwells and elevator shafts across floors. The fixed square meters meant that when increasing the square meters or dimensions of one room, other rooms on that floor had to decrease respectively. An example of this was the integration of the ergonomics knowledge from the PS Event 1 of the corridor. The knowledge transferred was new dimensions of the corridor to improve the work posture of the orderlies. The new dimensions meant a one-meter relocation of one corridor wall, as illustrated in Figure 7, thereby increasing the corridor's square meters. The relocation would have implications on the neighboring ventilation room.

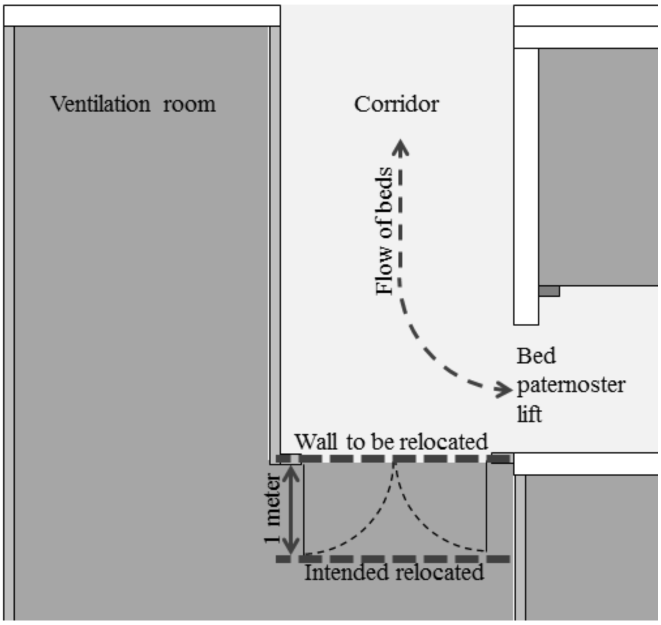

Figure 7: Relocation of the corridor wall.

The architect integrating the relocation of the wall described the situation as:

"The engineers have a huge [ventilation] facility placed behind that wall, including an area in front for servicing. When I need to move that wall, I have to confer with them [the engineers] about whether the wall can be an obstacle for the guy servicing the facility, because then I can't move the wall."

The interdependency between the corridor and the ventilation room revealed interdependency between the architect and the ventilation engineers. Earlier in the design process, the ventilation system showed not to occupy the entire ventilation room. So the engineers were able to introduce small adjustments, which made the wall relocation possible. However, the architect emphasized that if the relocation had been more than one meter, the ventilation room had to expand into neighboring rooms, resulting in a ripple effect.

The second interdependency of the bearing walls, stairwells and elevator shafts resulted in interdependency across floors. The engineer in charge of the construction provided an example:

"We had an entrance area, which the workers thought was a little squeezed because of a concrete wall. Their wish was, 'Can't we just move that wall?'... But this is a high-rise building with eight floors, and that wall was a bearing wall... It would take at least 250 hours to make the calculations on this [how to move the wall], and at that time we couldn't even say if the wall was actually possible to move. So it looks like something small [to change], but it's not, it's just not."

In this way the engineer emphasized that small changes within one room can have consequences for several floors and the engineers and architect in charge of designing those floors. In this situation, the interdependency resulted in the construction engineer rejecting the relocation of this particular wall.

4. Discussion

The aim of the study was to investigate the mechanisms behind transfer of ergonomics knowledge from PS events to hospital design and integration into hospital design. From the case study of six PS events, we identified intermediaries enabling ergonomics knowledge transfer, the integrated knowledge, and the main factors influencing the integration. In the following sections we discuss the findings and demonstrate the usefulness of the theoretical concepts of knowledge transfer and integration when planning and executing PS in workplace design.

4.1 Intermediary actors enabling ergonomics knowledge transfer

The intermediary actors, identified as the architect and engineer in PS Event 1, had the ability to transfer ergonomics knowledge from the PS events to the hospital design process. They had *boundary spanner* characteristics (Wenger, 2000), spanning over the boundary between the PS setting and the design setting. However, the intermediary actors had different application intentions of their obtained knowledge. The architect intended to apply the ergonomics knowledge directly in his work on changing the architectural blueprint. The engineer intended to apply the knowledge as part of the managerial coordination of the requirement specification. The different intentions showed how the individual actors *translated* (Gherardi & Nicolini, 2000) the knowledge in accordance with their specific context whether that was designing the hospital through architectural blueprints or through management and coordination.

Within the human factors and ergonomics field, intermediary actor abilities, such as boundary spanning and knowledge translation, have mainly been researched in relation to the ergonomists. Ergonomists have been identified as having the ability to mobilize knowledge from different domains (Broberg & Hermund, 2004), work across organizations, and facilitate meetings between actors (Béguin, 2011; Broberg & Hermund, 2007). In this study, the center employee with the OHS background could be seen as taking the ergonomist role - facilitating the PS events with several actors from different domains. The center employee had intermediary abilities during the PS events, but not in the subsequent knowledge transfer process. In that process, the architect and engineer took the intermediary role. So actors within the hospital design process, as well as ergonomists, can take the intermediary role when transferring ergonomics knowledge. Furthermore, the design actors have the advantage of being able to execute the hospital design, and in this way, they have the possibility to translate and apply the transferred ergonomics knowledge into the design. This is in contrast to the ergonomists who often are not executing the design. So when planning PS events, it is not only important to consider ergonomists as intermediary actors, but also to consider how design actors can be encouraged to take intermediary roles in the knowledge transfer.

4.2 Intermediary objects enabling ergonomics knowledge transfer

The intermediary objects identified were in the form of personal notes, descriptive documents and hand-drawn 2D sketches, all *codifying* (Gherardi & Nicolini, 2000) the knowledge created during the PS events. The codification was initiated by different actors who produced the intermediary objects. The intermediary objects in the PS Event 1 were produced by the architect, and in the other PS events by the center employees. The architect included solely the specific adjusted corridor dimensions in his personal notes and left out less tangible ergonomics focus points on safety issues for technical staff. The center employees included in the descriptions and 2D sketches a mixture of specific adjusted dimensions and less tangible ergonomics focus points, e.g. the focus point on discretion of patient data while still sustaining an efficient work practice. However, the center employees left out the reasons behind the specific dimension adjustments. The architect's documentation of only dimensions can be attributed to his background in building dimensioning and construction. The center employees' documentation of both dimensions and ergonomics focus points can be attributed to one of the center employee's background in OHS. In this way, the producers of the intermediary objects can be seen as a *filter mechanism* of the created ergonomics knowledge in accordance with their individual experiences and backgrounds.

The existing but limited research on ergonomics knowledge transfer from participatory activities to design processes has addressed objects with intermediary abilities. Barcellini et al. (2014) describe that results of simulations can take the form of "requirements that can be taken over by the designers." Broberg et al. (2011) describe that results of participatory activities can take the form of objects that "articulate a piece of design that has been materialized and can then be circulated in the organization," e.g. in a design organization. However, how the actors producing these intermediary objects have a filtering impact on the codified knowledge that has not been analyzed. A collaborative production of intermediary objects between ergonomists and design actors could utilize both the ergonomists' understanding of ergonomics focus points and the design actors' understanding of more tangible design dimensioning. Therefore, when planning PS events, involvement of design actors in intermediary object production should be considered.

4.3 Integration of ergonomics knowledge

In PS Events 1 and 5 all parts of the transferred ergonomics knowledge were integrated into the architectural blueprints. However, the integration related to PS Event 5 was "overdone" in the sense of not only replacing one bed with a chair, as indicated in the intermediary object, but in replacing all beds in the treatment room with chairs. The knowledge integration from PS Event 1 had a more direct nature without "overdone" parts. This more direct integration could be attributed to the fact that the actor producing the intermediary personal notes and the actor integrating the transferred knowledge were the same - namely the architect identified as the intermediary actor. That kind of double role of an actor was not observed in any of the other PS events. In the other PS events the center employees were the intermediary object producers, and architects, who did not participate in the PS events, were the knowledge integrators. Within the knowledge management field, the combination of intermediary actors and intermediary objects has been recognized as promoting knowledge transfer and integration (e.g. Yakhlef, 2007). The direct integration of knowledge from PS Event 1 could be an indication that such a combination might also be relevant in the transfer and integration of ergonomics knowledge from PS events to hospital design. In this way, the combination of intermediary actors and intermediary objects is relevant to consider in PS planning.

In PS Events 2, 3, 4 and 6, some parts of the transferred knowledge were integrated and others were left out. The non-integrated parts were both intangible ergonomics focus points and more tangible specific dimensions. Existing research on integration of ergonomics guidelines in engineering design show that ergonomics principles or general recommendations are hard to integrate by designers (Skepper et al., 2000; Wulff et al., 1999). Such ergonomics principles and recommendations can be related to the intangible ergonomics focus points of this study. An example from PS Event 2 was the non-integrated considerations of how discretion of patient information in the reception area could influence the work conditions. In contrast to ergonomics principles and recommendations, specific formulated ergonomics guidelines have shown to be more applicable by designers (Wulff et al., 1999). However in this study, specific dimension adjustments were still left out of the integration, e.g. the new position of a workstation in PS Event 4. Non-integrated dimension adjustments were transferred to the design process through both hand-drawn 2D sketches and descriptive documents. Therefore the type of ergonomics knowledge and the types of intermediary objects did not show a clear influence on the integration. This encouraged the further investigation of the hospital design project to identify other influencing factors.

4.4 Influencing factors on ergonomics knowledge integration

The two main influencing factors were identified: the already-set building dimensions and the interdependence of rooms. Both factors were products of early design decisions on the number of square meters per floor and the shape of the building. Those decisions were governmentally approved and therefore hard to change. The influencing factors are related to the nature of the hospital design process and can be conceptualized as *contextual constraints* (Burns & Vicente, 2000) or *lock-ins* (Béguin, 2011). Both concepts describe the constraints, which the designers had to work within when integrating ergonomics knowledge in the hospital design. These constraints sometimes led the designers to *transform* (Gherardi & Nicolini, 2000) the knowledge to make it fit within the constraints. However, this transformation was not expected by the center employees, who instead expected the function of the room to be the main design constraint. From the center employees' point of view, the knowledge created in the PS events was seen as joint decisions and somehow unquestionable. The intermediary objects codifying these decisions had a *closed* nature (Vinck et al., 1996). In contrast, the designers had to interpret and explore the ergonomics knowledge in order to transform it in accordance with the design constraints. The designers treated the received intermediary objects as *open* objects (Vinck et al., 1996).

Within ergonomics research, different kind of objects have been recognized as having the same intermediary abilities as identified in this study (Béguin, 2011; Broberg et al., 2011; Conceição et al., 2012; Garrety & Badham, 1999; Hall-Andersen & Broberg, 2013). However, how different actors can have different perceptions of the *closeness* and *openness* of the objects has not been analyzed. This study shows that the design constraints influence how the actors perceive the intermediary objects and transferred knowledge. Therefore, in the planning of PS it is important to aim for a *continual dialogue* between the producers of the intermediary objects and the designers. A dialogue might foster a matching of expectations of the *closeness* or *openness* of the intermediary objects, instead of solely relying on intermediary objects as one-way communication. Furthermore, taking into account design constraints prior to PS events could lead to creation of ergonomics knowledge that demands less transformation when integrated.

4.5 Limitations of the study

The study is based on a single case, comprising six PS events. This approach provided an in-depth investigation of the ergonomics knowledge transfer and integration related to these six PS events. The focus of the six PS events also limits the generalizability of the results (Thomas, 2011). However, the purpose of this study was to provide a case example where principles can be transferable to other similar contexts (Flyvbjerg, 2006). Understanding of the mechanisms behind the transfer of ergonomics knowledge from these six PS events and integration into hospital design can be valuable and transferable to smaller scale workplace design in other industries as well. The study shows the importance of not only focusing on the execution of PS events, but also of considering the transfer and integration of the PS outcomes for having an actual impact on the workplace design. For strengthening the focus on knowledge transfer and integration in relation to the PS method, we suggest further research on the relevance of other knowledge-transferring methods, such as communication technologies.

5. Conclusion

This study investigated the mechanisms behind ergonomics knowledge transfer from PS events and integration into hospital design. Six PS events contributing to the design of a major new Danish hospital were studied from the perspective of three research questions. The questions focused on how intermediaries enabled ergonomics knowledge transfer, the integration of the transferred knowledge, and the factors influencing the integration. We identified actors and objects with intermediary abilities transferring ergonomics knowledge from the PS events to the hospital design process. The producers of the intermediary objects functioned as a filter mechanism of the ergonomics knowledge created during the PS events. The integration of the transferred knowledge was not greatly affected by the form of the knowledge represented in the intermediary objects. Instead, the main influencing factors on the integration were: already-set building dimensions and interdependence of rooms.

The results of the study highlighted that the transfer and integration of ergonomics knowledge from PS events is an intertwined process composed of intermediary actors, intermediary objects, object producers, knowledge-receiving designers and two influencing factors as design constraints. For PS and other participatory activities to have an actual impact on workplace design, the ergonomist should not only focus on the facilitation and execution of the PS events, but also take into account the subsequent and intertwined process of knowledge transfer and integration during the planning of PS. We suggest the following implications for practitioners:

- Involve actors from the design process in the PS events with the aim of encouraging them to take intermediary roles in the ergonomics knowledge transfer.
- Involve actors from the design process in the production of intermediary objects. This provides more than one perspective when documenting the knowledge created during the PS events.
- Combine intermediary objects and intermediary actors for a more direct knowledge transfer and integration.

- Clarify design constraints with actors from the design process before the PS events. In this way, constraints can be taken into account during the PS events and not solely in the moment of knowledge integration.

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APPENDIX K: THE SUPPLEMENTING GUIDES FOR PRACTITIONERS

The appendix include first the brochure introducing participatory simulation to practitioner and second the four guides for practitioners.

Participatory Simulation

- A guide for facilitators

DTU PhD project conducted by Simone Nyholm Andersen at the Technical University of Denmark. Founded by the Danish Working Environment Research Foundation.

What is participatory simulation?

Participatory refers to worker participation in work system design. *Simulation* refers to the imitation of a real world work system. Therefore, *participatory simulation* means that workers are involved in imitating and designing their own future work system. Through participatory simulation the workers can explore design proposals and experiment with redesign suggestions. The method can be applied for lay-out arrangements of existing workspaces, renovation of facilities, and design of new workspaces.

What is a work system?

A work system is the system taking place at a workplace. It includes the physical space, the technologies applied, the organization of work, the work practices initiated, the workers, and the information they share. These aspects are interconnected and influence each other. Therefore, when designing workspaces, the design does not only concern the physical space but must take into account all aspects of the work system.

Why apply participatory simulation in work system design?

Existing studies show that the design of work systems has a huge impact on the ergonomic conditions[1]. Additionally, studies show that involvement of workers in work system design results in integration of ergonomics considerations. Participatory simulation is a central method for such worker involvement. Ergonomics work system design results in reduced sick days, work-related disorders and psychosocial pressure, and at the same time increases productivity, efficiency, and quality.[1] The improvements result in a return of investment on 6-24 months.[2]

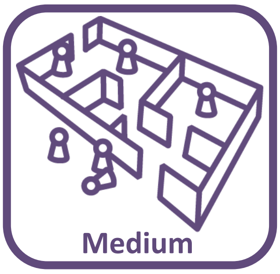
[1]Hignett, S., Carayon, P., Buckle, P., Catchpole, K., 2013. Human factors and ergonomics in healthcare. Ergonomics 56.

[2]Hendrick, H.W., 2008. Applying ergonomics to systems: Some documented "'lessons learned.'" Appl. Ergon. 39.

“Because the simulation was physical the LEGOs came alive and you became the role you played. It resulted in serious play and created a room for innovation where people shared their insights”

- Facilitator of table-top simulation.

The four elements of participatory simulation



A medium is a model that visualizes and represents the future work system. The visualization is often in relation to the physical space and technologies.

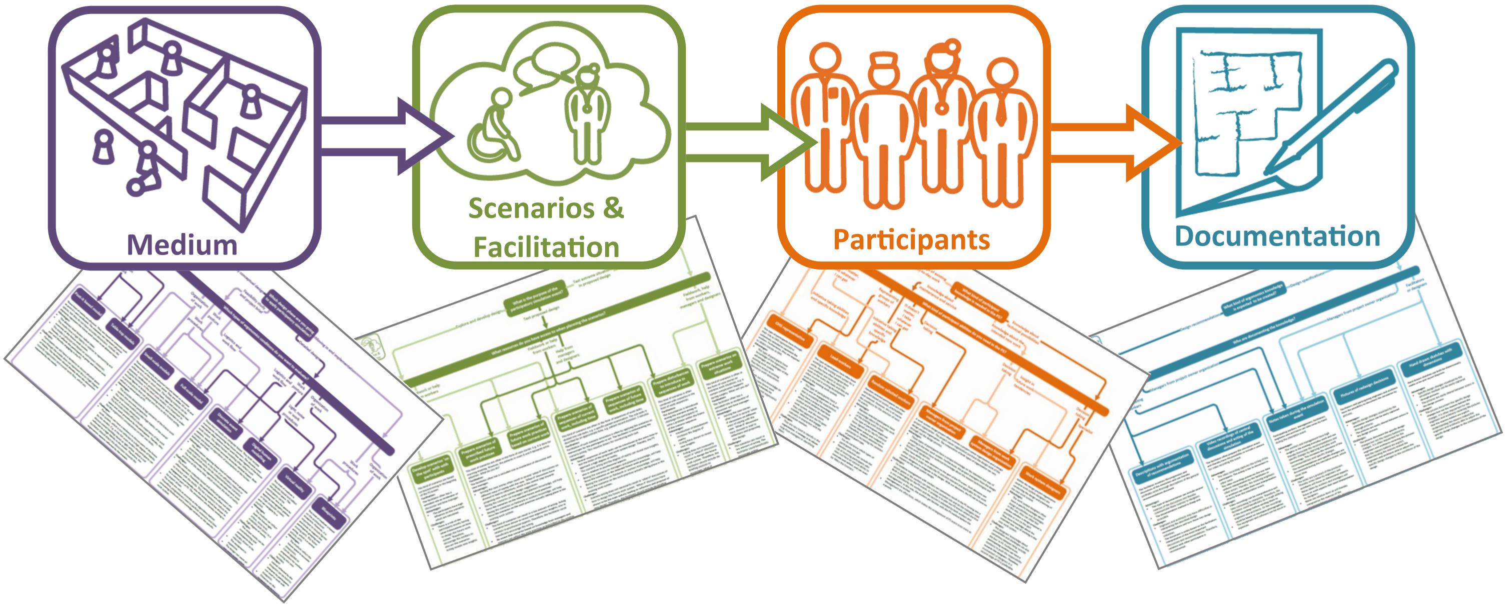
A scenario is a story of a possible work situation in the future work system. It often includes the organizational and social part of the work system, e.g., in the form of division of work. Facilitation of the simulation event is related to how the scenario is applied.

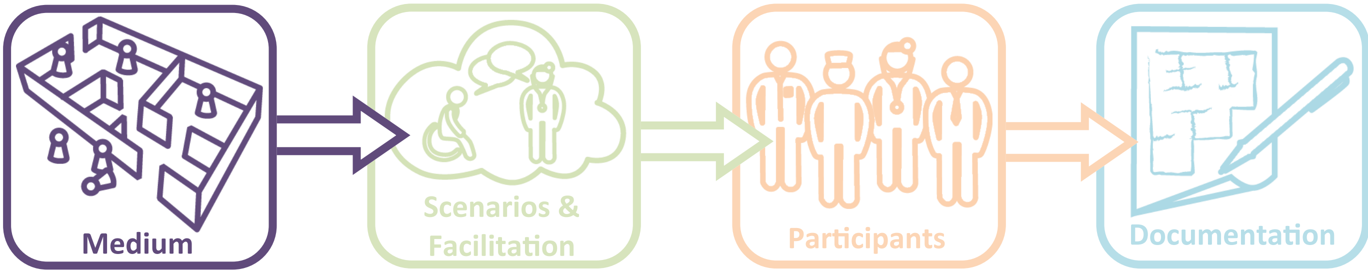
Participants are the actors involved in simulation of the future work system. The future workers are central, but also management, project owners, engineers, and architects are relevant to involve. The different participants bring different knowledge into the simulation.

Simulation outcome is often in the form of design specifications and redesign proposals. The outcome has to be documented and communicated to actors in the design organization with the aim integration into the work system design.

Four guides for planning participatory simulation

The four elements of participatory simulation have to be considered when planning simulation events. The four participatory simulation guides enclosed can assist in taking deliberate choices in the planning. By applying the guides, you can plan your own participatory simulation event. Answer the questions of the guides in accordance with your particular simulation aim. Remember that combination of several answers is often relevant. The following pages elaborate each of the guides in the sequence indicated below.





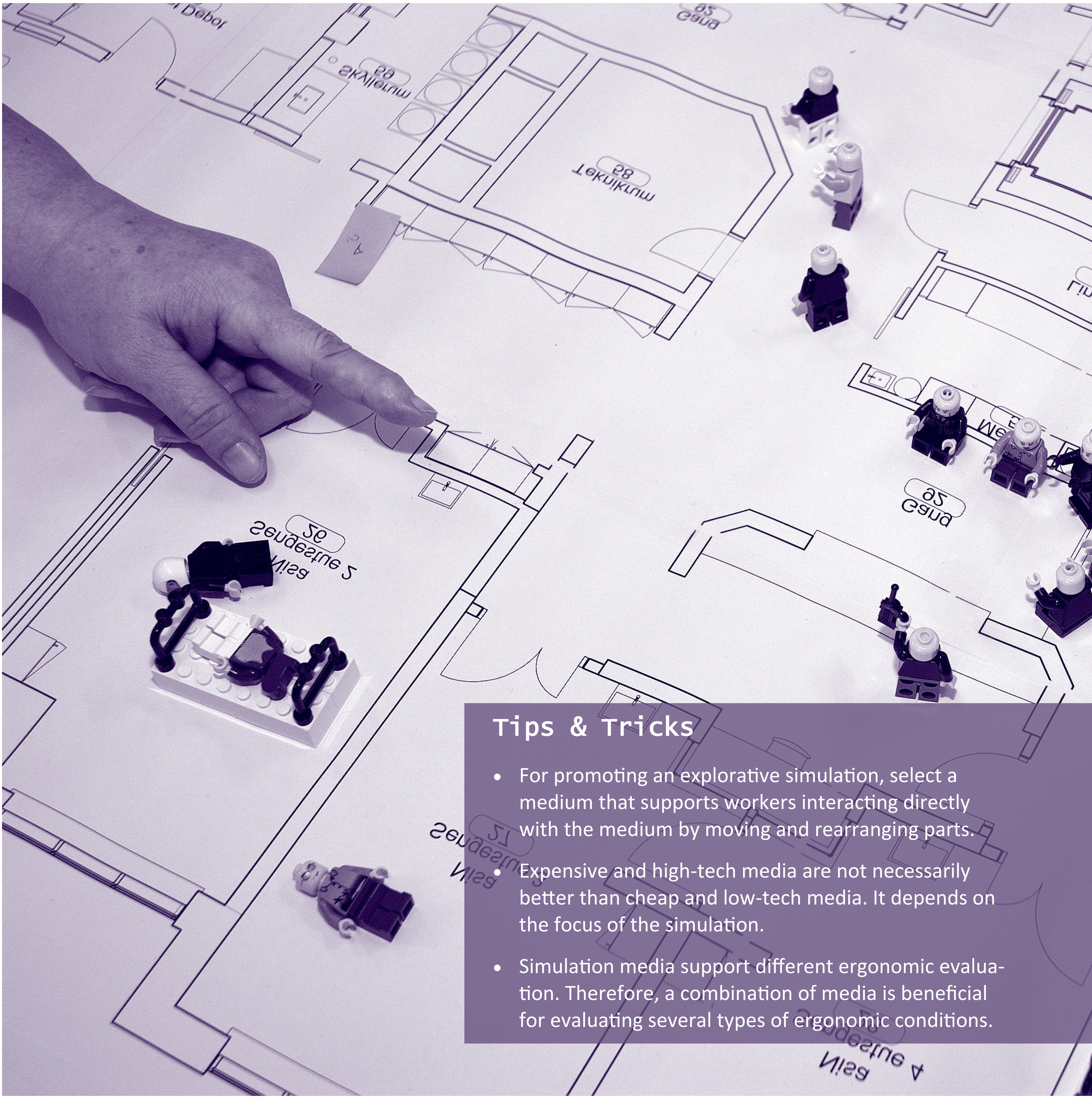
Choose the simulation medium in relation to...

...the design phase

Different design phases have different focuses. The early conceptual design focus is on “the big picture” and the overall relations between functions in the new work system. The derailed design focus on each single room and the specific layout. Different media support different focus and are therefore relevant in different design phases.

...the desired ergonomics evaluation

Because different media support different focus, they also support evaluation of different ergonomic conditions. One medium does not support evaluation of all ergonomic conditions, and therefore the medium has to be selected in accordance with the desired ergonomic evaluation.



Tips & Tricks

- For promoting an explorative simulation, select a medium that supports workers interacting directly with the medium by moving and rearranging parts.
- Expensive and high-tech media are not necessarily better than cheap and low-tech media. It depends on the focus of the simulation.
- Simulation media support different ergonomic evaluation. Therefore, a combination of media is beneficial for evaluating several types of ergonomic conditions.

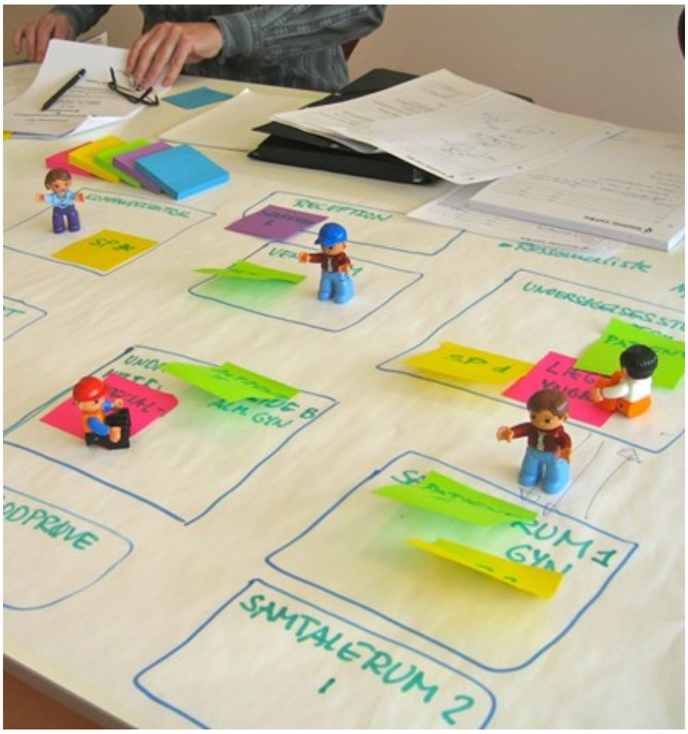
Examples of simulation media

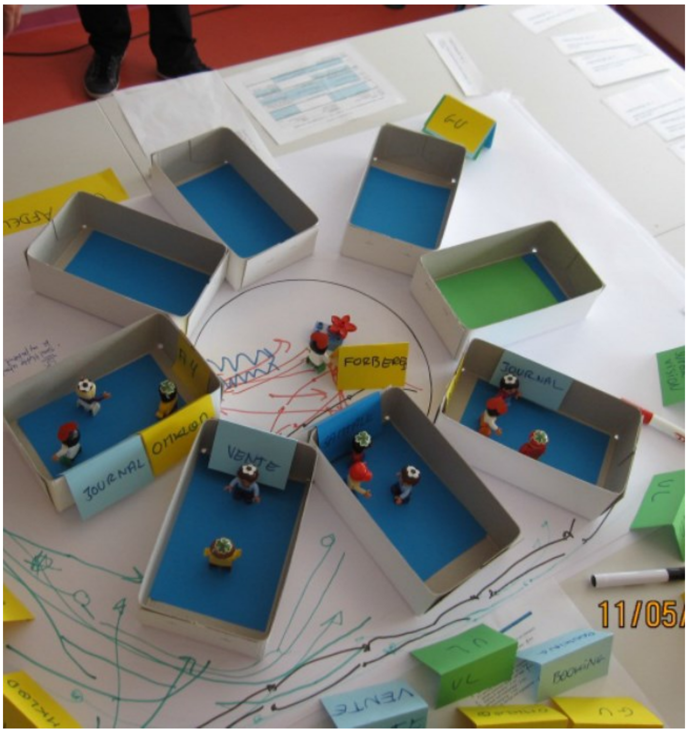
Post-it based model

This medium is based on Post-its and LEGO figures. The Post-its represent functions in the future work system. The LEGO figures represent workers.

Table-top model

This medium is based on cardboard boxes and LEGO figures. The boxes represent future rooms. The LEGO figures represent workers. The medium does not represent the accurate dimensions of the physical space, but instead the overall concept.





Small-scale model

This medium represents the future physical workspace in small-scale dimensions. It can be based on LEGO bricks or cardboard. Furthermore, it is often combined with LEGO figures representing the workers.

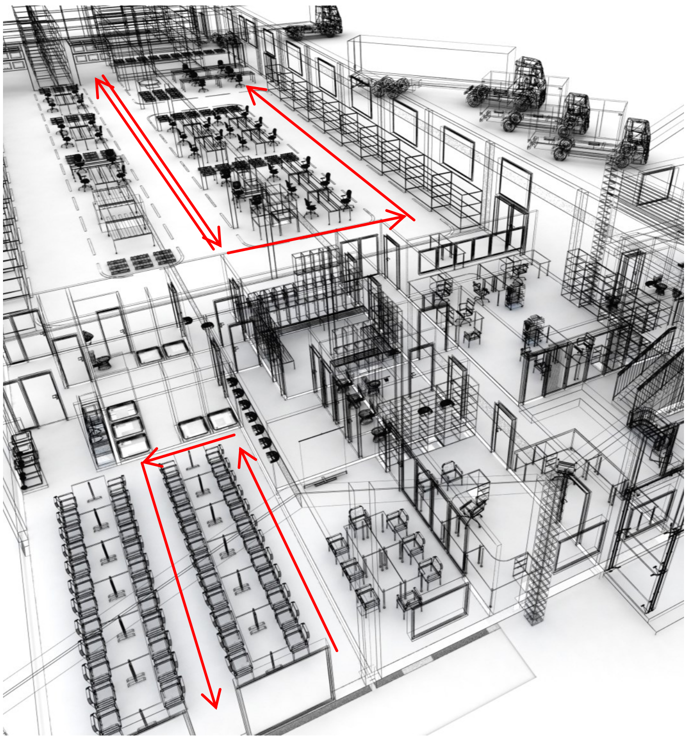
Full-scale mock-up

This medium represents the future physical space in full-scale. It can be based on chipboard and foam bricks. Participants can explore the layout with their own body.

Examples of simulation media

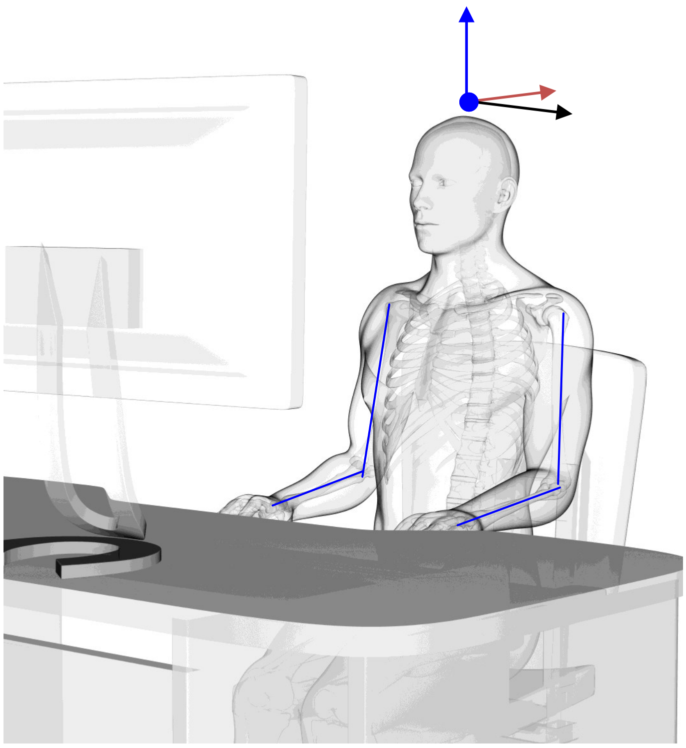
Discrete event simulation

This medium is computer-based and includes mathematical models on work processes. Work flow and logistics can be precisely simulated. The medium can represent the layout of the future work system or only represent a sequence of work tasks.



Digital human modelling

This medium is computer-based and includes mathematical models on the strain and stress loads on an average human body. This enables precise simulation of reach distances and physical impacts on the human body.

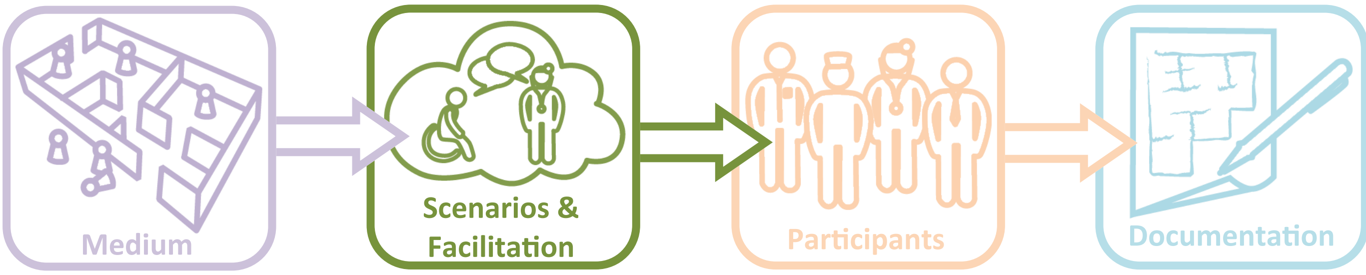


Virtual reality

This medium is computer-based and relies on stenographic glasses or large projectors. The participant is “immersed” into a digital and full-scale environment. The digital environment can be a whole building through which participants can navigate.

Blueprints

This medium is based on a printout of the architectural blueprint, representing the physical space in 2D and to a small scale. Sometimes it includes LEGO figures to support acting of scenarios.



Choose the scenarios and facilitation in relation to...

...the simulation purpose

The purpose of the simulation event can vary. Sometimes the purpose is to test specific work system designs. Other times the purpose is to develop and explore a design. Here some types of scenarios are suitable for testing design and others are suitable for exploring design. Furthermore, different types of scenarios need different facilitation styles. The facilitation can be strictly controlled or more secluded monitoring.

...the available resources

Development of a scenario requires knowledge about the existing or the intended work. The facilitators of simulation events do not always have this knowledge. Therefore, it is important to include resources, e.g., the management, who have the required knowledge. Furthermore, fieldwork in the existing work system can also be a resource to develop a scenario. The resources available have an impact on the types of scenario developed.

Tips & Tricks

- Be aware that the different types of scenarios also support different design phases, e.g., an open scenario supports the early design where the purpose is to develop and explore designs.
- The scenarios should encourage participants to take initiative and reflect on the ergonomic conditions of the work system design. This promotes participants proposing redesign initiatives and design specifications.

Examples of simulation scenarios

Scenario development "on the spot"

This type of scenario is developed "on the spot" of the simulation together with the simulation participants. It is not necessarily documented, but can be narrative stories from the participants. Furthermore, it can be continually elaborated during the simulation event. Therefore, this type of scenario does not require extensive preparation by the facilitators.

Case stories

Case stories often characterize a work situation to be solved during the participatory simulation. The story can reflect either the work in the existing work system or the intended work in the future work system. The intended future work is often based on prescribed procedures. The facilitator often needs help by management, workers, or field work in the scenario development.

MODTAGELSE AF PATIENT I AFSNITTET

Holger meldes fra akutmodtagelsen. Al kommunikation vedr. Holger foregår via klinisk logistik. Det fremgår bl.a., at han er bariatrisk patient. Holger har fået optaget journal og lagt behandlingsplan. Han har fået en seng, som han er i, når han ankommer til afsnittet. Alt andet specialudstyr skal spores via håndholdt device og hentes. Medicin, som ikke er i standardsortiment og blod bestilles i EPJ og ankommer med rørpost.

En anden patient skal udskrives og stuen skal rengøres og indrettes til Holger, inden han kommer.

OPGAVEN

1) Overvej, hvad der gøres, inden Holger ankommer. (F.eks. udskrivelse, rengøring, finde og bestille stol/bækkenstol i stor størrelse, bestille/hente blod, medicin, andet?). Gennemgå gerne scenariet med brug af voksdugen.

2) Hvilke muligheder for løft i kvalitet og effektivitet bliver I opmærksomme på, når I sammenligner med jeres nuværende rammer og arbejdsgange?

3) Hvad skal I ændre, for at kunne skabe dette løft? Jeres arbejdsgange, jeres organisering, jeres kultur, jeres samarbejdsrelationer

Tasks sequences

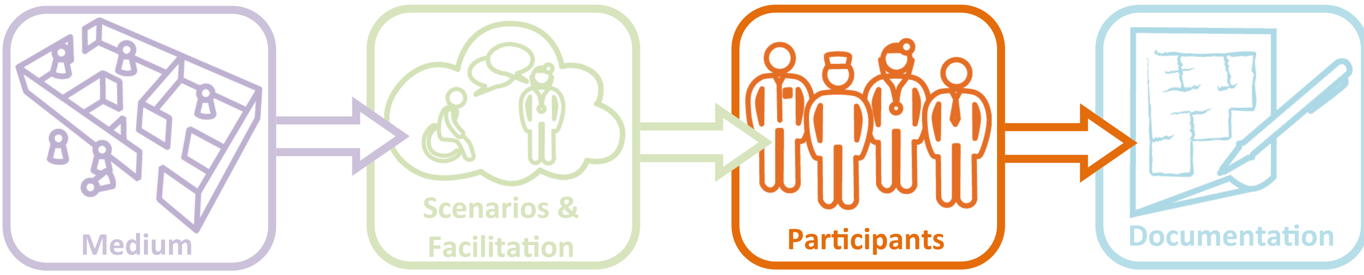
The task sequences can include a time factor, e.g., a third of real time. By applying timers, the sequences can be enacted. Several different sequences can be enacted on the same time and adds reality to the simulation. The sequences can be based on the work in the existing work system or the intended future work in the form of prescribed procedure.

Min	Patient	Sygeplejerske	Læge
3	modtagelse i recepti-on.	Forberedelse af stuen Hjælper på gan-gen	Forberedelse. Læser patientjour-nal.
9	venteværelse		
6	Hentes/kaldes til samtale/ undersøgelsesstue – (transport)	Henter patient.	
6	Samtale sygeplejer-ske	Samtale sygeple-jerske	
9	journaloptagelse		journaloptagelse
6		Forberedelse til GU– UL - behandling	
3	Afklædning		Diktering af jour-nal del 1
1	kommer på undersø-gelseslejet	Hjælper patient	Gør sig klar til undersøgelse. Handsker på, bord og udstyr.
6	GU og ultralyd	GU og ultralyd	GU og ultralyd

Unanticipated events

Work often does not taking place as expected, but includes unanticipated events. These events can be combined with the other types of scenarios. In this way, the events can be disturbances in task sequences or in case stories. The unanticipated events increase the reality of the simulation.

	Forstyrrelser
1	Du har brug for supervision, tilkald en erfaren læge.
2	Der skal gås audit på afdelingen og du bliver nødt til at deltage.
3	Der opstår komplikationer under undersøgelsen.
4	….



Choose the simulation participants in relation to...

...the needed knowledge

The simulation participants bring their professional knowledge into the simulation. In participatory simulation, knowledge sharing is central to proposing redesign and design specifications. In relation to the specific simulation purpose, different types of knowledge can be desired. Participants can have different backgrounds and experiences, and thus different knowledge. Therefore, the simulation participants should be selected based on their individual knowledge.

...the needed abilities

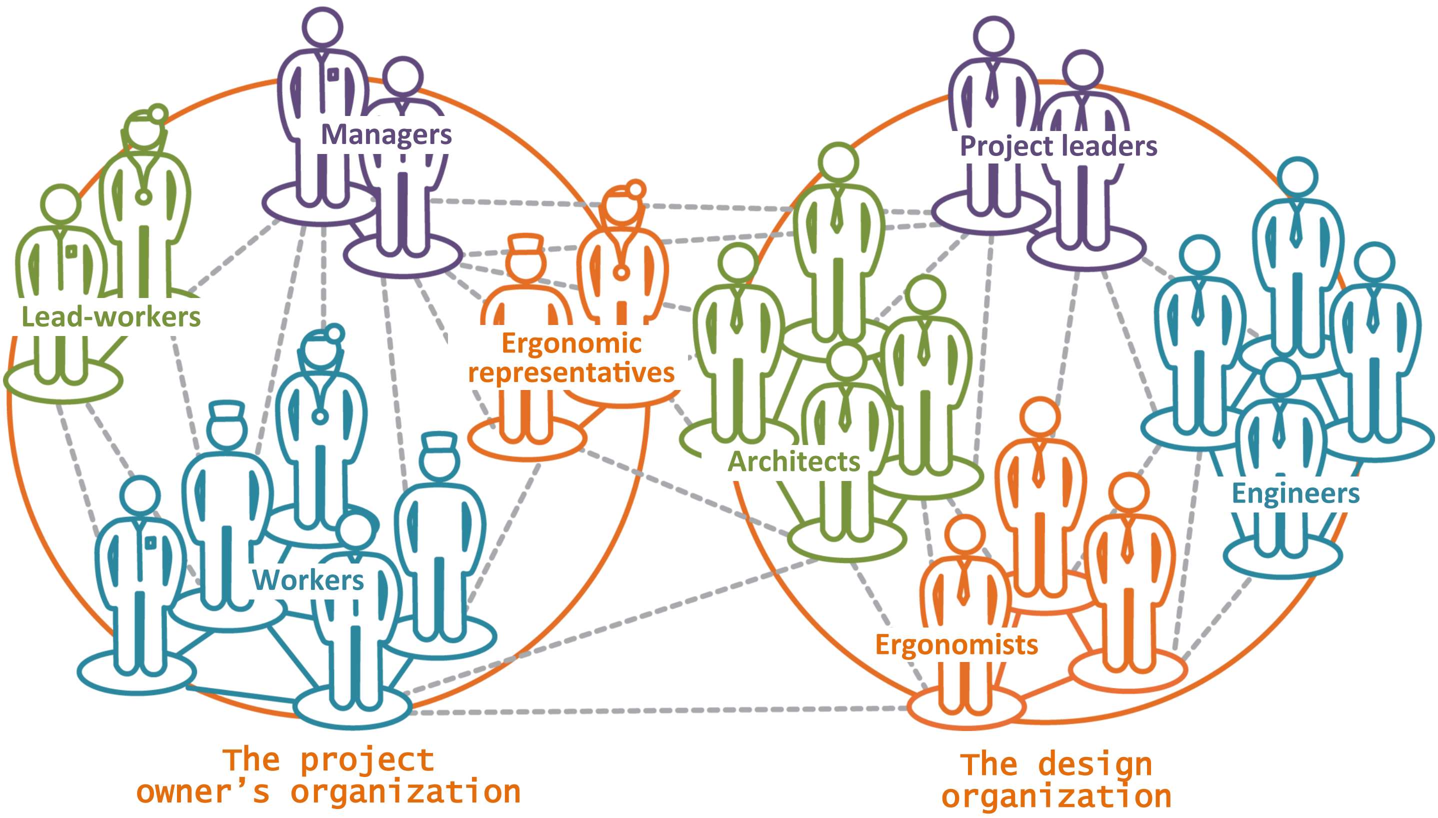
Participants have different abilities, e.g., decision-making or acting as representative. In relation to the purpose of the simulation event, different participant abilities are relevant. Therefore, the simulation participants should be selected based on the abilities needed in the individual simulation event.

Tips & Tricks

- Be aware that power struggles can occur when both workers and managers are involved. Make a clear facilitation strategy in these situations.
- Involvement of both designers and workers can result in the workers retracting from suggesting redesigns and pushes the design responsibility toward the designers. However, workers often have valuable knowledge. Therefore, remember to encourage the workers to contribute.

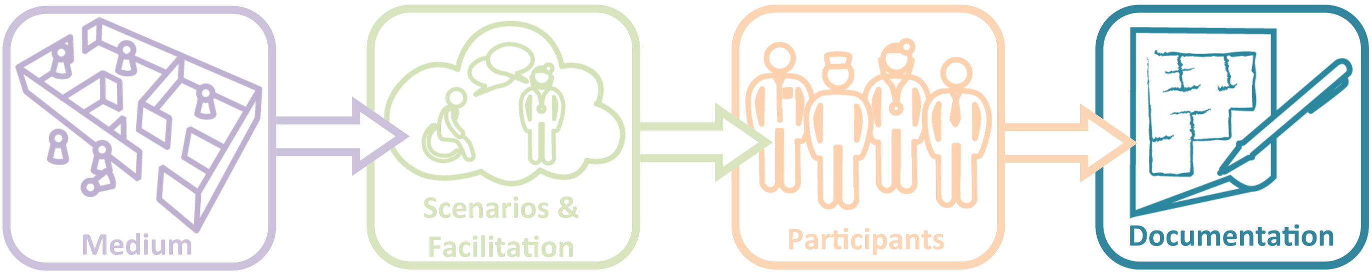
Examples of simulation participants

The figure shows an overview of possible simulation participants. Participants are relevant from the project owner's organization and the design organization. However, both organizations are complex and interconnected, which can be a challenge to navigate.



"We are three cadasters that are going to merge, so we prioritize that we involve workers from all three in the mock-up simulation. In this way the mock-ups also becomes some kind of fusion of cultures"

- Facilitator of full-scale mock-ups simulation.



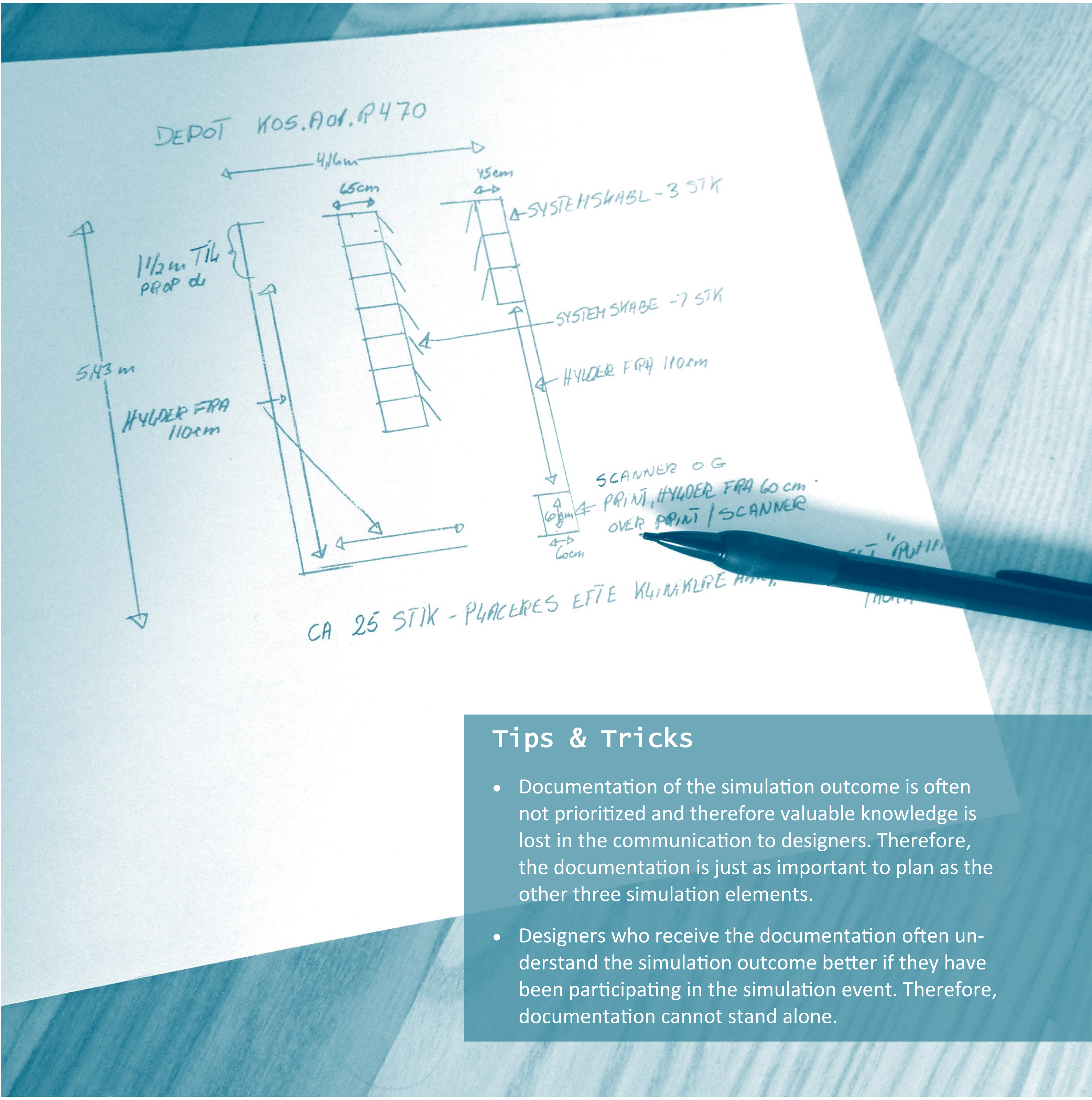
Choose the documentation in relation to...

...the simulation outcome

The simulation outcome takes the form of design specifications or redesign suggestions. The outcome needs to be documented to be communicated to work system designers. Different types of outcome are not necessarily suitable for being documented in the same manner. Therefore, it is important to choose documentation types in accordance with the expected simulation outcome.

...the person who does the documentation

Simulation participants can document the outcome in different ways. However, some participants are better at doing some type of documentation than others. Therefore, the documentation type should fit the person that is going to document the simulation outcome.

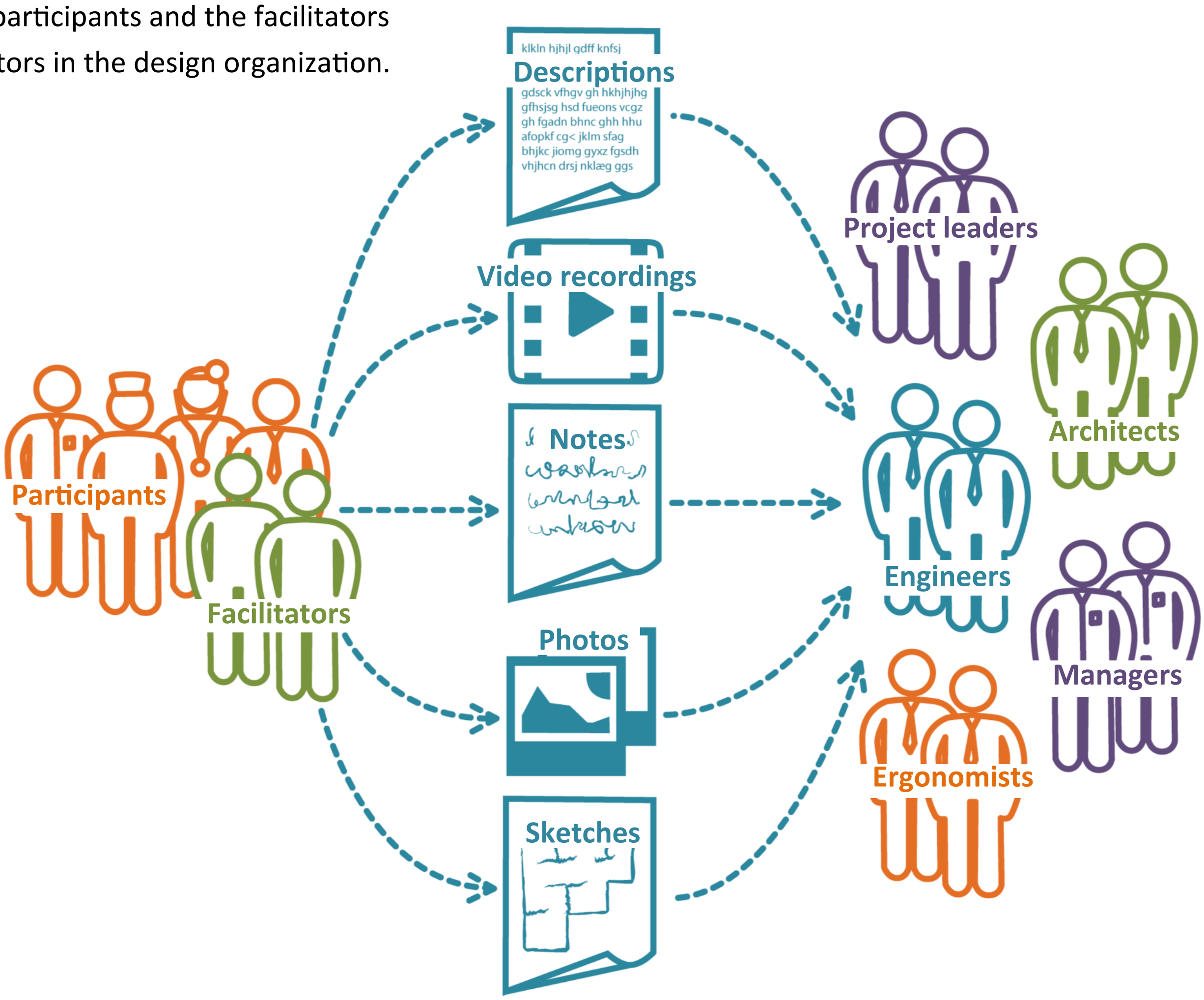


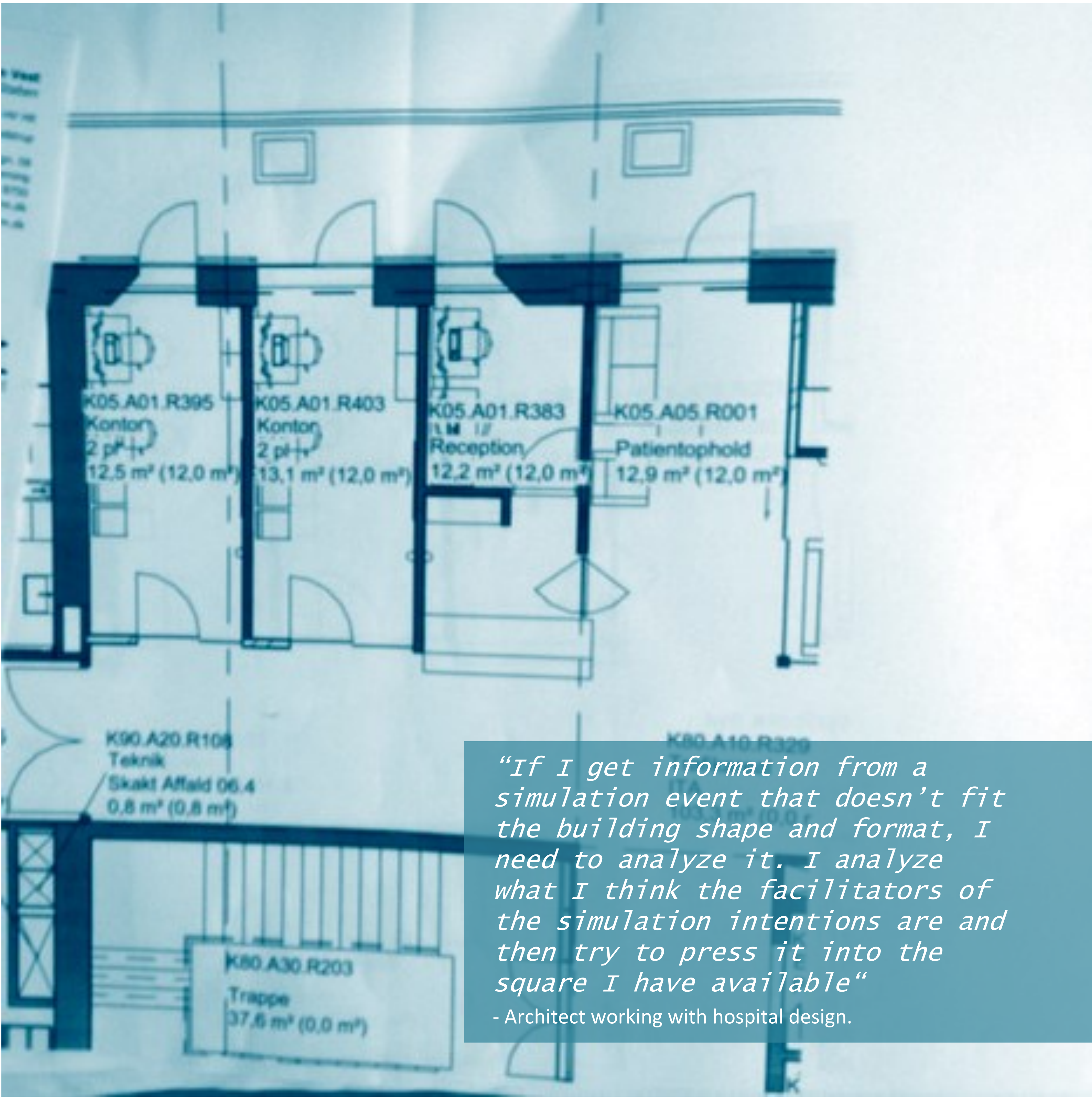
Tips & Tricks

- Documentation of the simulation outcome is often not prioritized and therefore valuable knowledge is lost in the communication to designers. Therefore, the documentation is just as important to plan as the other three simulation elements.
- Designers who receive the documentation often understand the simulation outcome better if they have been participating in the simulation event. Therefore, documentation cannot stand alone.

Examples of documentation types

The figure shows an overview of possible documentation types. The different types can transfer and communicate the simulation outcome from the simulation participants and the facilitators to actors in the design organization.

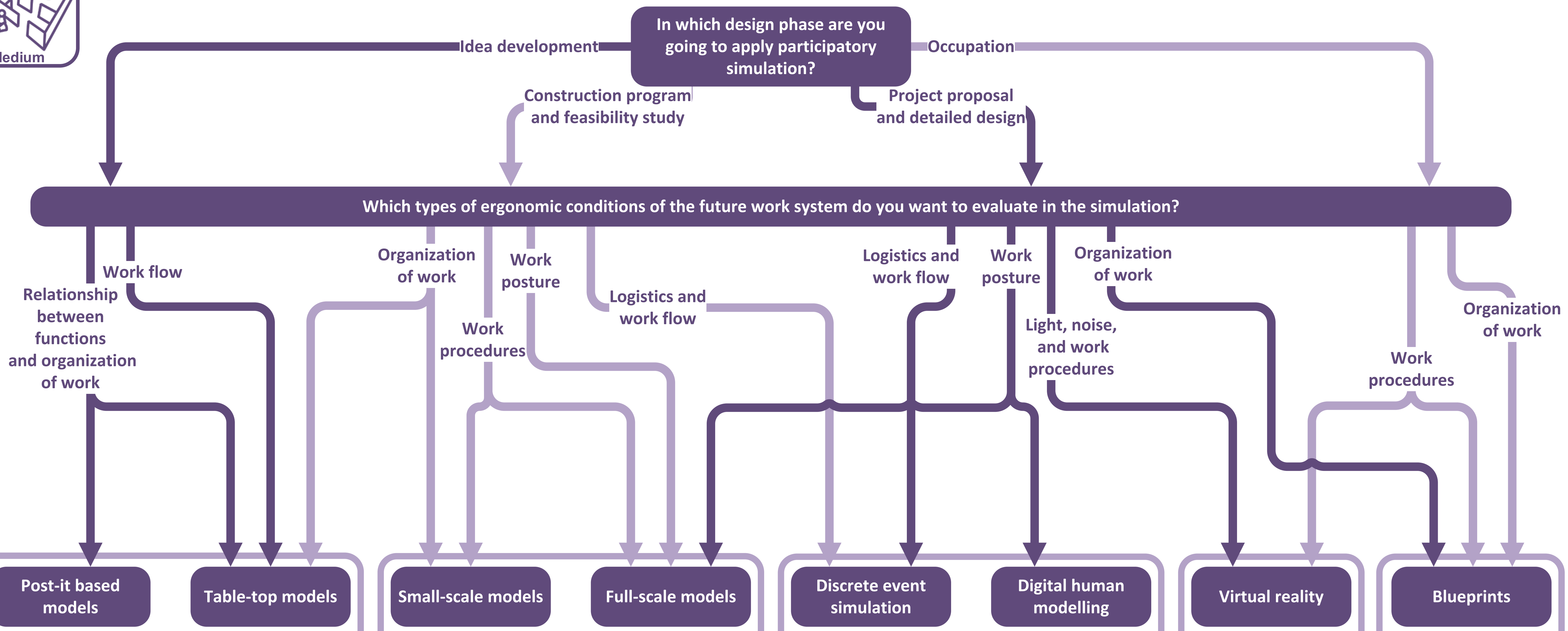




"If I get information from a simulation event that doesn't fit the building shape and format, I need to analyze it. I analyze what I think the facilitators of the simulation intentions are and then try to press it into the square I have available"

- Architect working with hospital design.

Medium



These media are abstract and therefore not dimensionally stable. Read more in the brochure, page 8.

Advantages:

- The abstract models make the proposed work system design look "un-finished" and thus also negotiable. This fosters exploration of the design and proposal of redesign.
- The media are physical and based on well-known materials. In this way, the media afford the participants to interact directly with them by moving parts. This fosters engagement.

Challenges:

- Participant can have a tendency to discuss the specific dimensions of the workspace even through the media are not dimensionally stable. In such situations, the facilitator should direct the discussion towards ergonomic conditions supported by the media, e.g., organization, work flow and the relationship between functions.

These media are physical and based on accurate dimensions. Read more in the brochure, page 9.

Advantages:

- The accurate dimensions bring the physical workspace into accurate perspective.
- The small-scale models provide overview of the overall layout in accurate dimensions.
- The full-scale models afford that the participants can experience the workspace and work procedures on their own body.

Challenges:

- Participants can start discussing parts of the future work system, which the models do not represent. For instance, the full-scale models do not show the relationship between Functions in several rooms because the full-scale models often only can represent a few rooms at a time. Therefore, the facilitator should direct the discussions towards ergonomic conditions supported by the medium.

These media are computer-based including assumptions of the human behavior and body. Read more in the brochure, page 10.

Advantages:

- The media generate quantitative results, in the form of efficiency measures or body loads, which easily can be compared between different designs.
- The media provide the opportunity for simulating several work tasks in parallel with the purpose of identifying overlaps and breakdowns.

Challenges:

- Skilled programmers are required. Therefore, participants are often not able to interact directly with the media.
- The media are only as accurate as the assumptions behind them. Therefore, the precise results do not always reflect all aspects of the real world system.

This medium is computer-based. Read more in the brochure, page 11.

Advantages:

- The medium can reflect both the future light inflow and noise level.

Challenges:

- It can be overwhelming for participants to be immersed into.
- The equipment is expensive.
- The design can seem 'too ready' which demotivates radical ideas.

This medium is based on architectural blueprints. Read more in the brochure, page11.

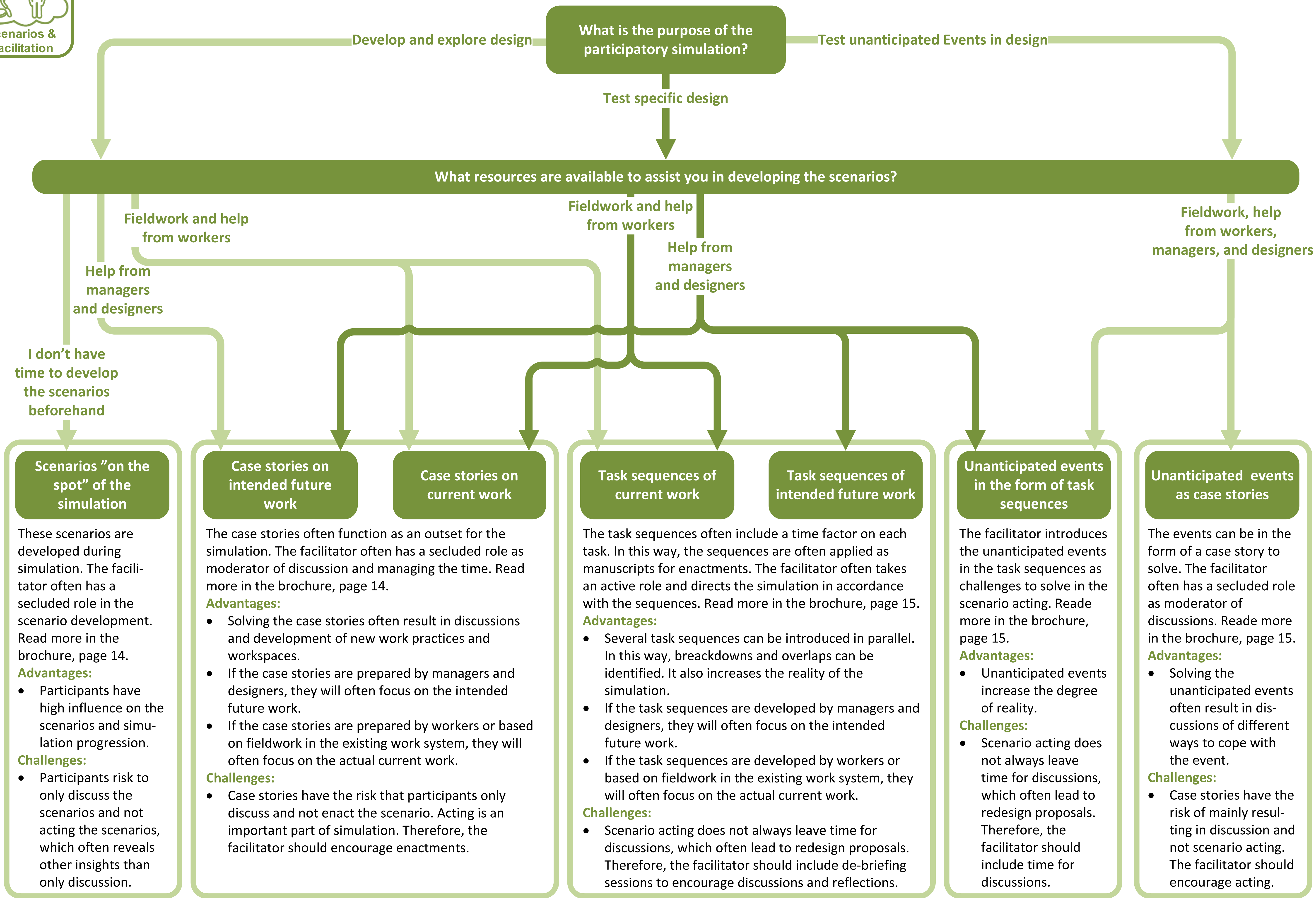
Advantages:

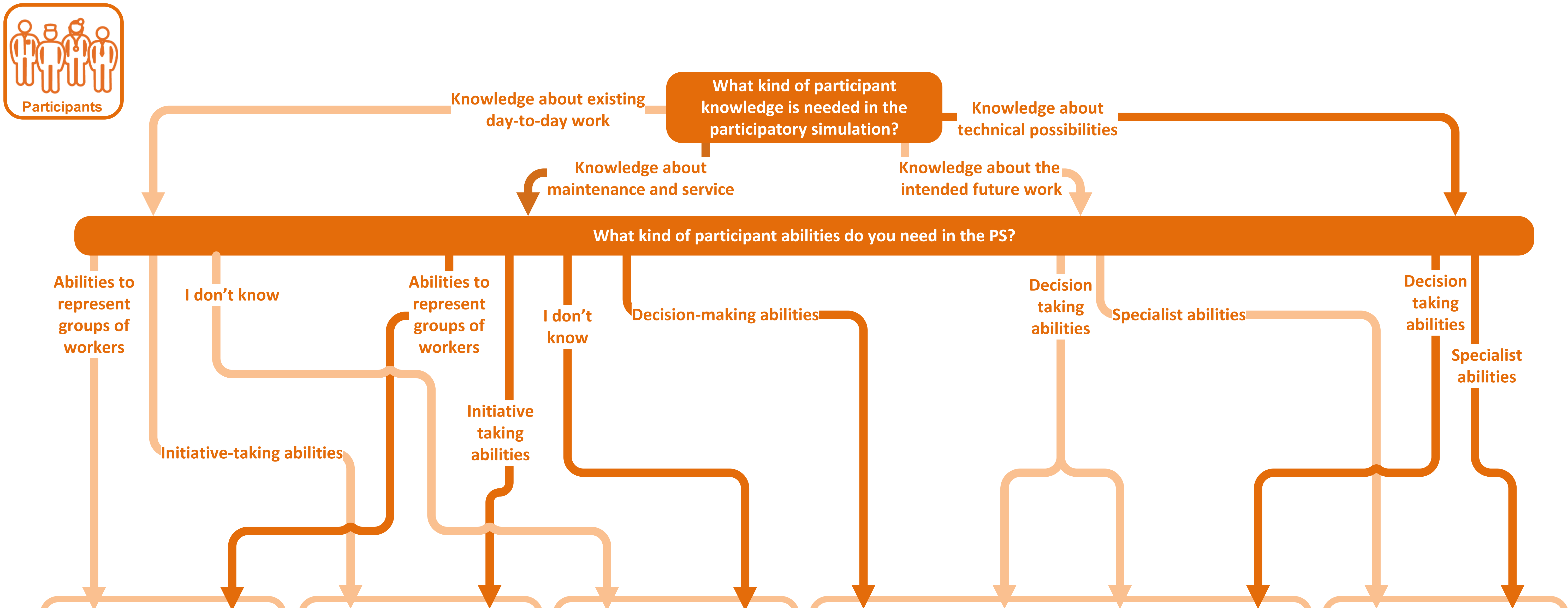
- Can be applied for preparing workers that are going to move into new facilities.

Challenges:

- Can be hard to interpret by participants who are not used to working with blueprint.
- Distances on the blueprint can be hard to relate to reality.

Scenarios & Facilitation





Ergonomic representatives

Ergonomic representatives are collectively selected to represent the workers. See more in the brochure, page 18.

Advantages:

- They have knowledge of ergonomic advantages and challenges of the existing work system.
- They have access to ergo-nomic investigations of the existing work system.

Challenges:

- They might not have knowledge on the inten-ded future work, and will therefore focus on ergonomic challenges of the existing work.

Lead-workers

Lead-workers are workers who take initiative in everyday work to develop their own work practices. They have ideas and can see possibilities. See more in the brochure, page 18.

Advantages:

- Their initiative-taking will often result in progression of the simulation.
- They have unique know-ledge of improvement initiatives and potentials in the existing work system.

Challenges:

- They are hard to identify in the organization. A strategy is to obtain help from managers.

Randomly selected workers

They are often selected because of practicalities. See more in the brochure, page 18.

Advantages:

- They have knowledge about the everyday work.
- By selecting workers ran-domly, you get a variety of workers. This includes the worker types who perhaps would not have signed up without being asked.

Challenges:

- You do not know what type of worker you get.
- You risk that you get worker types who do not take initiative. They can even be "Mary the contrary."

Managers from project owner's organization

Project leaders from design organization

Often participatory simulation includes decisions. Therefore, participants with decision-making abilities and responsabilities are important to include. See more in the brochure, page 18.

Advantages:

- They have a knowledge of the intended future work. Furthermore, project leaders from the design organization have technical knowledge about new work tendencies.
- They have the abilities and responsabilities of taking decisions "on the spot" of the simulation. This is important to ensure the relevance and design impact of the simulation.
- Involvement of management and project leaders can ensure buy-in from managerial levels in organizations.

Challenges:

- Combining management with workers can result in power games or the workers stepping into the background. Both situations are damaging for the simulation. Therefore, the facilitator should ensure that both workers and managers are contributing evenly in the simulation.
- Management are often busy, which can turn the arrangement of simulation event into a puzzle.

Designers

They are conducting the work system design. See more in the brochure, page 18.

Advantages:

- They can often define whether a design proposal is possible or not "on the spot" of the simulation.
- They have technical knowledge about new ways of working.

Challenges:

- Their specific technical knowledge can decrease workers' motivation for suggesting new designs. In this way, the workers can have a tendency to push the design responsibility toward the designers.

Documentation

What kind of outcome is expected from the participatory simulation?

Suggestions and recommendations

Specifications and requirements

Who are documenting the knowledge?

Facilitators

Participating workers

Managers from project owner's organization

Managers from project owner's organization

Facilitators and designers

Descriptions of suggestions and recommendations

The facilitator follows the entire simulation event and can thereby develop a decription of the outcome. See more in the brochure, page 22.

Advantages:

- Descriptions can include several nuances and arguments.
- Descriptions are cheap and easy to communicate to the designers.

Challenges:

- Designers may have difficulties in interpreting the descriptions and turn the suggestions and recommendations into design initiatives.
- The descriptions are solely based on the facilitator's interpretation of the simulation outcome. Therefore, validation from other participants is recommended.

Video recordings of central parts of the simulation

The facilitator prepares the simulation and has the possibility to include a video camera. See more in the brochure, page 22.

Advantages:

- Video recordings capture scenario acting, which is hard to document in other ways.
- Video recordings preserve the simulation process and the receiving actors can in this way make their own interpretations.

Challenges:

- Video recordings can be time-consuming to interpret. Therefore, the facilitator can preferably indicate the passages which include relevant input to the designers.
- The video equipment can result in expenses.

Notes that are conducted during the simulation

Notes can be conducted by hand during the simulation event. See more in the brochure, page 22.

Advantages:

- Workers and management have insights in everyday work and can formulate specifications and recommendations by applying the terminology applied in the existing work system.
- The outcome of the simulation event is documented during the event and this saves time.

Challenges:

- The notes are a product of the producer and will therefore sometimes be less understandable by other people.
- Notes are relatively short and will thereby compromise nuances.

Pictures of redesign specifications and recommendations

Facilitators follow the entire simulation and have possibility for taking picture. Furthermore, designers can also take pictures of the specific design specifications. See more in the brochure, page 22.

Advantages:

- When the participants change parts of the simulation medium for proposing redesign, pictures can easily capture the changes.
- The pictures are easily shared between actors in the design process.

Challenges:

- Pictures document the design changes, which can be turned into design specifications and requirements. But pictures do not show the reasons behind the changes.

Sketches with specifications and recommendations

Hand drawn sketches can both be quick conceptual overviews and dimensionally stable drawings. See more in the brochure, page 22.

Advantages:

- Sketches can be produced during or right after the simulation, which saves time.
- Sketches can illustrate specific design specifications and requirements to a high degree of details.
- Sketches can include written explanation and argumentation.

Challenges:

- Facilitators are not necessarily educated in architectural layout sketching as the designers are. Therefore, a common way of sketching has to be agreed upon.