Tampere University

TIINA JOUPPILA

# Exploring Virtual Reality as a Tool for Co-Design in Healthcare Facilities

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# ABSTRACT

This dissertation focuses on the use of information systems methods and tools to enable healthcare professionals to participate in the design of healthcare facilities. The methods and tools that support the collaboration and visualization of the design will put healthcare professionals on a more equal footing in the design process.

The methods and tools used in the design was co-design and full-scale virtual prototypes of spaces. Co-design enables healthcare professionals to bring their occupational and experience-based expertise to the design. Virtual prototypes enable professionals to experience the room and test its usability, unlike construction blueprints. Virtual prototypes were used earlier than in the traditional design process.

This dissertation also studies the usability of methods and tools in the design and the outcome of the design based on end-user satisfaction. Interviews and questionnaires were used to assess the methods and tools used. Post-occupancy evaluation, which is based on evidence-based design, was utilized in the assessment of the outcome.

The healthcare professionals could participate more effortlessly with the methods and tools used and bring their occupational and experience-based expertise to the design. The healthcare professionals could evolve the virtual prototypes with their feedback to meet their spatial and functional requirements. Additionally, co-design with multi-occupational groups in walk-in virtual environments were considered profitable, and the requirements of various occupations could be evaluated in groups. The co-design in groups evolved and accelerated, generating feedback for further design.

Healthcare professionals considered the participation useful and regarded designing in groups a good method. Designing in a group and the shared virtual environment produce a growth in knowledge and evaluation ability in the design process. When comparing pre- and post-occupancy evaluations, there was a statistically significant difference in all topics. However, when comparing satisfaction with the design outcome between participants and non-participants in the design, there was no

statistically significant difference between these two groups. The impact of collaborative design and virtual prototypes on general satisfaction in the design process requires additional studies. Healthcare professionals considered post-occupancy evaluation important, as they could give feedback on new facilities and functions.

Keywords: participatory design, co-design, evidence-based design, post-occupancy evaluation, virtual reality, virtual prototypes

# TIIVISTELMÄ

Tässä väitöskirjassa tutkitaan tietojärjestelmätieteen menetelmien käyttöä terveydenhuollon ammattilaisten osallistumisen tukena terveydenhuollon tilojen suunnittelussa. Yhteistyön tukeminen ja suunnitelmien visualisointi ovat menetelmiä, jotka tuovat terveydenhuollon ammattilaiset tasa-arvoisempaan asemaan suunnitteluprosessissa.

Suunnittelussa menetelmänä käytettiin informaatioteknologian menetelmänä yhteisöllistä (co-design) suunnittelua ja luonnollisen kokoisia virtuaalisia prototyyppejä tiloista. Yhteisöllinen suunnittelu mahdollisti terveydenhuollon ammattilaisille menetelmän, jonka avulla he voivat tuoda ammatillisen ja kokemusperäisen tiedon suunnitteluun. Virtuaaliset prototyypit puolestaan antoivat mahdollisuuden kokea tilan ja testata sen käytettävyyttä toisin kuin tilan pohjakuva. Virtuaalisia prototyyppejä voitiin käyttää aikaisemmassa vaiheessa perinteistä rakennussuunnittelua.

Väitöskirjassa tutkittiin myös käytettyjen menetelmien soveltuvuutta suunnitteluun ja suunnittelun lopputulosta käyttäjätyytyväisyyden pohjalta. Käytettyjen menetelmien arvioinnissa käytettiin haastatteluja ja kyselylomakkeita. Lopputuloksen arvioinnissa käytettiin käyttöönoton jälkeistä arviointia, joka perustuu näyttöön perustuvaan suunnitteluun.

Terveydenhuollon ammattilaiset pystyivät osallistumaan käytettyjen menetelmien avulla paremmin suunnitteluun ja tuomaan siihen ammatillisen ja kokemusperäisen tiedon. Terveydenhuollon ammattilaiset pystyivät palautteellaan kehittämään virtuaalisia prototyyppejä virtuaaliympäristössä vastaamaan tilallisia ja toiminnallisia tarpeita. Myös yhteisöllinen suunnittelu moniammatillisissa ryhmissä koettiin hyväksi menetelmäksi ja eri ammattiryhmien vaatimuksia tiloille pystyttiin arvioimaan ryhmissä. Ryhmässä tehty suunnittelu paransi ja nopeutti palautteen saamista jatkosuunnittelua varten.

Terveydenhuollon ammattilaiset pitivät osallistumista hyödyllisenä ja ryhmässä suunnittelua hyvänä menetelmänä. Ryhmässä tapahtuva suunnittelu ja yhteinen virtuaalinen tila lisäsi henkilökunnan tietämystä ja arviointikykyä suunnitteluprosessissa. Vertailtaessa vanhojen ja uusien tilojen toimivuuden arviointituloksia tapahtui kaikissa arviointikohteissa tilastollisesti merkitsevä muutos. Kun taas verrattiin suunnitteluun osallistuneiden ja ei-osallistuneiden henkilöiden tyytyväisyyttä lopputuloksiin, ei näiden ryhmien välillä ollut tilastollisesti merkitsevää eroa minkään arviointikohteen osalta. Yhteisöllinen suunnittelu ja virtuaalisten prototyyppien merkitys suunnitteluprosessissa vaatii lisätutkimuksia. Terveydenhuollon ammattilaiset kokivat tärkeäksi myös, että he voivat osallistua käyttöönoton jälkeiseen arviointiin ja antaa palautetta uusista tiloista ja toiminnoista.

Avainsanat: osallistava suunnittelu, yhteisöllinen suunnittelu, näyttöön perustuva suunnittelu, käyttöönoton jälkeinen arviointi, virtuaalitodellisuus, virtuaaliset prototyypit

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Seinäjoki, 4 July 2025

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# ABBREVIATIONS AND DEFINITIONS

| | |
|---|---|
| 3D | Three-dimensional |
| CAVE | Computer-Assisted Virtual Environment |
| EBD | Evidence-based design |
| HMD | Head-mounted display |
| IS | Information systems |
| IT | Information technology |
| PD | Participatory design |
| POE | Post-occupancy evaluation |
| VE | Virtual environment |
| VP | Virtual prototype |
| VR | Virtual reality |

# ORIGINAL ARTICLES

1. Wahlström, M., Aittala, M., Kotilainen, H., Yli-Karhu [Jouppila], T., Porkka, J., and Nykänen, E. (2010). CAVE for collaborative patient room design: analysis with end-user opinion contrasting method. *Virtual Reality*, 14(3), 197–211.

2. Yli-Karhu [Jouppila], T. (2014). Impact of Virtual Environment Utilization in Post Occupancy Evaluation. International Conference on Research on Health Care Architecture. *Conference Proceedings ARCH 14*, 19–21.11.2014. Aalto University, Finland, 111–125.

3. Tiainen, T. and Jouppila, T. (2019). Use of Virtual Environment and Virtual Prototypes in Co-Design: The Case of Hospital Design. *Computers*, 8(2), 44. DOI: 10.3390/computers8020044.

4. Jouppila, T. and Tiainen, T. (2021). Nurses' Participation in the Design of an Intensive Care Unit: The Use of Virtual Mock-ups. *Health Environments Research & Design Journal*, 14 (2), 301–312. DOI: 10.1177/193758672093540.

5. Jouppila, T. (2022). Staff participation in design with multiple tools: Impact on design and POE results. *Health Environments Research & Design Journal*, 15 (2), 315–330. DOI: 10.1177/19375867211060734.

# AUTHOR'S CONTRIBUTION TO THE ARTICLES

I I participated in planning the research procedures with the other members of the HospiTool research group. My contribution was interviewing nurses and analysing the results of the nurses' participation in the CAVE sessions. The corresponding author of the article was Mikael Wahlström. He wrote the first manuscript of the article. The other co-authors commented on and rewrote the draft.

II I was the only author.

III Tarja Tiainen, PhD, wrote the theoretical background and supervised the process. I participated in and analysed the practical case. I planned and conducted the practical development work with the Evicures research group. Tiainen and I wrote the article together.

IV I was responsible for the writing as the corresponding author, and co-author Tarja Tiainen, PhD, supervised the process. The theoretical part and conclusion were written together with Tiainen. I planned and conducted the practical development work with the Evicures project group. My contribution was the survey data gathering, processing, and analysis, and writing up the results.

V I was the only author.

# 1 INTRODUCTION

The aim of this dissertation is to elaborate on Information systems (IS) collaborative methods and virtual tools facilitating healthcare professionals' participation in the design of healthcare facilities. In this dissertation, the collaborative methods introduced are participatory design (PD) and co-design. Additionally, the computer-assisted virtual environment (CAVE) virtual tool, which creates full-scale virtual prototypes (VP) of various hospital rooms, is presented. The participation of healthcare professionals in the design of healthcare facilities is important due to their knowledge and professional skills and competencies in daily workflows. It is also important to develop methods in the design of healthcare facilities that support participation for all stakeholder groups and facilitate the use of expertise and competence (Sanders and Stappers, 2008; Keys et al., 2017; Carthey, 2020a).

## 1.1 Background and research environment

In many studies, healthcare researchers bring up challenges regarding the participation of healthcare professionals in design and construction, and they study solutions to enable participation when designing healthcare facilities. **First**, there are not many opportunities for healthcare professionals, like nurses, to participate in design, as managers usually represent their units (Stichler, 2016). Although it is not always obvious that nurses should be included in design groups, their participation has been evaluated to be highly important (Cesario, 2009; Thompson et al., 2012; Redden and Evans, 2014; Keys et al., 2017), even in the early design phase (Elf et al., 2016). A study by Reno et al. (2014) found that healthcare professionals' participation improves the design and avoids post-occupancy renovations. The participation of healthcare professionals was quite rare earlier (Rechel et al., 2009; Stichler, 2016), but the frequency has grown this century as the participation methods have evolved (Keys et al., 2017). Additionally, facilities are built for a long lifespan and the healthcare professional's opportunity to participate may occur only once or twice during a working career (Thompson et al., 2012; Clark, 2014).

**Second**, the traditional design and construction process has not taken sufficiently into account non-design orientated stakeholders. Healthcare professionals lack competence in reading technical documents and two-dimensional drawings (Keys et al., 2017), and they

lack sufficient knowledge and competencies for successful involvement during the design and construction processes (Clark, 2014; Reno et al., 2014). Furthermore, there are difficulties in communication between healthcare professionals and designers due to different terminologies and professional language (Cesario, 2009; Reno et al., 2014). At present, the situation has improved considerably due to team skills, meeting strategies, design orientation, and advanced visualization tools (Keys et al., 2017). Versatile digital and virtual information models support end-user participation. Such tools include full-scale physical and virtual mock-ups, building information models, and other modelling programs that support the end-users' understanding of the design situation better when compared to looking only at the blueprints (Tutt and Harty, 2013; Reno et al., 2014; Wingler et al., 2019). Side by side with physical mock-ups, virtual mock-ups have increased, enhancing flexibility, cost-effectiveness, and the digital storage of mock-ups (Durham and Kenyon, 2019; Kalantari and Neo, 2020; Shultz and Jha, 2021).

**Third,** research is needed to assist healthcare professionals and designers to apply the best recommendations in design and construction. Evidence-based design (EBD) from the 1980s conducted multidisciplinary research that study the effects of the healthcare environment on the patients' healing and well-being, the healthcare staff's well-being and performance, and the functional, economic, and sustainable perspective of design (Ulrich et al., 2008). Testing the performance of a healthcare facility design with a post-occupancy evaluation (POE) provides evidence of the best practices in the design and construction and shows the level of end-user satisfaction with the facility (Halawa et al., 2020).

**Finally**, healthcare facilities include an enormous amount of technology, and care establishments process and transfer information (Bayramzadeh and Aghaei, 2021). Building service systems, like ventilation and cooling, provide a healthy environment for recovery and work (Berry and Parish, 2008; Redden and Evans, 2014; Bayramzadeh and Aghaei, 2021). Information technology (IT) and digitalization affect the work of healthcare professionals, and it is important to take their insights and experiences into account in design (Lavander et al., 2020).

## 1.2 Objectives and research questions

In IS, the collaborative method of PD has been available in design for many decades in cases where the knowledge of the end-users is important (Bjerknes and Bratteteig, 1995; Bratteteig and Wagner, 2016). PD is largely utilized in the design of IS but has expanded to other design fields, like social media technology, medical technology, and the healthcare sector (design, facilitating learning for hospital personnel and patients) (Halskov and Hansen, 2015). In PD, democracy is one of the main themes, resulting in the better

acceptance of the system, more effective use of the system, and increased participation in decision-making within the organization (Bjerknes and Bratteteig, 1995; Kujala, 2003).

Based on PD, another method has developed, co-design (Sanders and Stappers, 2008). Co-design refers to the situation where designers and end-users without any design education work together in the design development process (Sanders and Stappers, 2008). The participants bring their expertise to the process, and the designers and researchers provide tools to express ideas and comments. PD and co-design methods have been used successfully in the design of systems that need the knowledge and practical experience of users (Clement and Van der Basselaar, 1993; Halskov and Hansen, 2015), and in the design of healthcare facilities and processes (Watkins et al., 2008; Elf et al., 2016; Reay et al., 2017).

Collaborative design uses multiple tools to support participation (scenarios, mock-ups, future workshops, design games, prototyping) (Kensing and Blomberg, 1998). The tools were initially physical and tangible, but virtual reality (VR) technology enables expansion to virtual prototyping, simulation, and visualization. VR can be defined as the computer-generated simulation of a three-dimensional (3D) image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment (Healthcare Information & Management Systems Society, 2025). VR can be immersive or non-immersive depending on the feeling or sense of presence, i.e. participants perceive themselves as being inside the presented virtual environment (VE). The VE platform determines the immersiveness; in natural size walk-in VE, stereoscopy, a wide field of view, and high interactivity are critical elements to achieve immersiveness (Paes et al., 2017). Immersive VEs include head-mounted displays (HMD) and CAVE. Non-immersive forms include desktop computer monitor and large-screen stereo projection systems of various levels (Kim et al., 2013). VPs are virtual correspondences to physical mock-ups, and they can be of different fidelities (detailed/non-detailed), which influence the evaluation of the participants.

The objective of this dissertation is to study and apply the methods of collaborative design, to study the use of walk-in VE, and to research the practices of EBD. The cases of this dissertation examine how to improve end-users' opportunities to participate in the design of healthcare facilities by taking advantage of their expertise and experience. At first, we observed individual participants and multi-occupational groups in a virtual environment, namely their experience of walk-in VE and their capabilities to evaluate different features of VPs of rooms. Secondly, we used EBD in compiling design criteria and evaluating end-user satisfaction on present and future healthcare facilities.

The chosen walk-in VE was CAVE. CAVE is an immersive walk-in VE where the visualization software renders a full-scale stereoscopic image on each display wall of

CAVE, synchronously and properly skewed according to the perspective of the viewer's position and orientation (Cruz-Neira et al., 1992). CAVE is a room with three walls, a ceiling, and a floor (Cruz-Neira et al., 1992). It enables the presence of multiple participants simultaneously to realize the design (Kim et al., 2013). CAVE was chosen because it offers the opportunity to have a multi-user shared experience, face-to-face communication, and interaction for collaborative design (Vasconcelos et al., 2019).

In this dissertation, the VPs themselves and working in these VPs were evaluated by individuals and multi-occupational groups using collaborative methods. The aim was to understand how the evaluation in CAVE happens and how the participants experience working alone or together in design, and to ascertain what features and functions can be tested. Collaborative design was used to evaluate the more equal opportunities to participate in the design and consider whether the different vantage points of the participants were acknowledged. To assess the effects of using these new methods, it was important to study the advantages and disadvantages of the methods, gather feedback from the participants, and determine which features participants could reliably be evaluated in CAVE. Also, the study investigated which spatial properties and features in the design appear to be important in CAVE.

The last stage of this dissertation studies end-user participation in all phases of design and construction and the participation impact on end-user satisfaction. Usually in studies of healthcare design, end-users participate only in a few phases. The third case fills the research gap, involving healthcare professionals in all phases of design, construction, and evaluation, and the use of co-design, VPs, and evaluation tools from EDB.

The research questions are:

**RQ1. How can a walk-in VE be utilized in the collaborative design of healthcare facilities?**

and

**RQ2. How can the outcome of collaborative design with a walk-in VE be evaluated?**

The main results of this dissertation argue that co-design with full-scale VPs has many advantages. Healthcare professionals could participate in the design within their expertise and evolve the design. They were satisfied with the methods and tools. Co-design with full-scale VPs has an impact on general end-user satisfaction. There was no statistically significant difference between participation and non-participation in the design in terms

of end-user satisfaction of the last two cases. This result needs further research because generally participation in design is supposed to raise end-user satisfaction (Kujala, 2003).

## 1.3 The structure of the dissertation

The structure of the dissertation is the following. Chapter 2 introduces three phenomena: collaborative design methods, the VR platforms and prototypes, and EBD tools. All of these are used variously in the cases of this dissertation. Collaborative design and VR were used in the design phase, and EBD assisted in the definition of the requirements for healthcare facilities and in evaluating the design outcome and end-user satisfaction. In Chapter 3, the research methods are introduced. The three cases were from real design and construction projects for a Finnish hospital. In all these cases, healthcare professionals participated in the design and evaluated and evolved VPs of forthcoming spaces. The results of the preceding case impacted the direction of the next case. The research methods of the cases are introduced, and the third case is introduced more thoroughly in terms of the methods and tools. Chapter 4 presents the five articles included in this dissertation. In Chapter 5, the findings of the cases are introduced. The main findings of the cases indicate that co-design with VPs seems to be useful for healthcare professionals. Also, the use of VPs enables visualization earlier in the design process. Furthermore, participation in design adds end-user satisfaction to the design outcome, even among those who did not participate in the design process. Chapter 6 presents the discussion, scientific implications, and recommendations for practice. It also evaluates the reliability, validity, generalizability, and limitations of the studies. The discussion ends with recommendations for future studies. Chapter 7 presents the conclusion of this dissertation.

# 2 LITERATURE REVIEW

The literature review combines three fields of research together, which form the basis for this dissertation. These three fields of research are collaborative design, VR, and EBD. In collaborative design, we elaborated PD and co-design. The VR platform was CAVE, where full-scale VPs of healthcare facilities were presented. EBD provided the criteria for the design and a method to evaluate end-user satisfaction and design outcome. In this chapter, the utilization of PD and co-design in IS are introduced, explaining how these methods are expanded to other disciplines where the knowledge and experience of workers is essential (Kujala, 2003; Sanders et al., 2010; Halskov and Hansen, 2015). The tools used in PD and co-design are also presented, but the focus is on full-scale VR tools. As those methods and tools are utilized in the design of healthcare facilities, some knowledge of EBD is essential due to the impact of healthcare facilities on patients, staff, and hospital activities. EBD studies the impact of healthcare environment on the patients' healing and well-being and the healthcare staff's well-being and performance, providing research findings and best practises for the design of healthcare facilities (Ulrich et al., 2008).

All these fields of research support end-user participation in the design of healthcare facilities and contribute to the quality of design. PD and co-design contribute collaborative design, and CAVE enables individuals and multi-occupational groups to evaluate the VPs of rooms under consideration. EDB tools, like predetermined quality criteria and pre-design evaluation, provide source information for design, and POE assesses the design outcome (Elf et al., 2015; Halawa et al., 2020).

All these three fields have been considered important by healthcare professionals and researchers. Recent studies in healthcare facility design combine fields of research (Figure 1) – collaborative design with PD and co-design, VR tools, and EBD tools with the purpose of developing end-user participation and improving the quality of design (Fay et al., 2017; McLaughlan and Liddicoat, 2018; Carthey, 2020a; Carthey, 2021; Halawa et al., 2020; Kalantari and Neo, 2020). In their review, Kalantari and Neo (2020) studied fully immersive VEs in interior design research, and their future research directions include enhancing the realism and immersiveness of fully immersive VEs and promoting multiuser studies. They state that EBD has become particularly influential in healthcare settings (Kalantari and Neo, 2020).

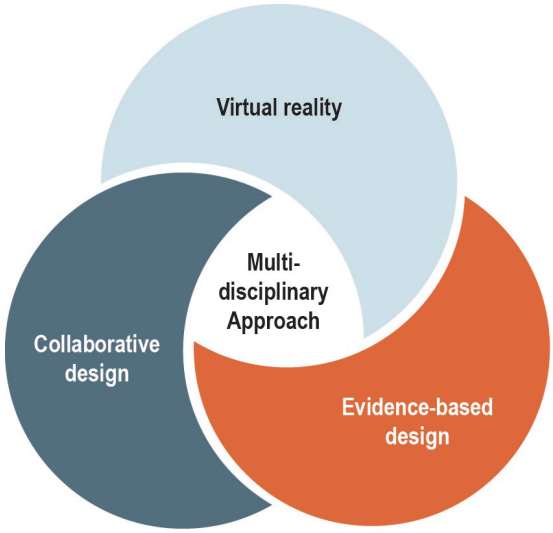


Figure 1. Combination of the researched fields in this dissertation. Design: Sanna Kontiola

## 2.1 Participatory design and co-design

Both PD and co-design are collaborative design methods. "Collaborative" refers to producing by or involving two or more parties working together (Oxford Dictionary of English, 2025). Elf et al. (2015) suggest the collaborative planning and design process between stakeholders, and shared decision making based on EBD and end-users' perspectives. Collaborative design needs visualization tools, which can be physical or virtual (Roupe et al., 2020). As the healthcare facilities have become more complex and technologically advanced, it is important to achieve good collaboration and understanding between stakeholders (Roupe et al., 2020). The term "collaborative design" can be used as an upper-level term, as there are more methods than PD and co-design used in design (like integrated design and concurrent engineering) (Savolainen, 2019).

The constituent reasons in PD for user participation are improving the knowledge upon which systems are built, enabling participants to develop realistic expectations, reducing resistance to change, and increasing workplace democracy by giving the staff the right to participate in decisions that are likely to affect their work (Bjerknes and Bratteteig, 1995). In PD, the approach is that designers invite future users to participate in all phases of the design with a pragmatic view that simplifies implementing the design result (Bratteteig and Wagner, 2016). For example, there were two multiannual projects, DEMOS and UTOPIA, with the target of creating designs with skilled workers and designers in

cooperation computer artefacts, and those projects inspired research up until the 1990s (Bjerknes and Bratteteig, 1995). DEMOS had four enterprises (a repair shop, a newspaper, a metal factory, and a department store) in which workers and trade unions, with the assistance of researchers, observed the implementation and use of new technologies (Ehn, 1988). In UTOPIA, the objective was to develop powerful skill-enhancing skills for graphic workers (Ehn, 1988).

Democracy is one of the main themes in PD, resulting in the better acceptance of the system, the more effective use of the system, and increased participation in decision-making within the organization (Kujala, 2003). In PD, end-users have direct contact with designers (Kujala, 2003). PD has expanded to other fields where direct contact with end-users and their know-how is crucial. Examples of such fields are space design, product development, industrial design, architecture, and service and transformation design (Kujala, 2003; Sanders et al., 2010; Halskov and Hansen, 2015). User involvement in PD is stronger than in other approaches where users are seen as providers of information, commentators, or objects of observation (Kujala, 2003).

There is not short and accurate definition of PD. In their review, Halskov and Hansen (2015) identified three general definitions based on how participation is organized. The three definitions are implicit, the users' point of view, and mutual learning (Halskov and Hansen, 2015). Whereas Luck (2018) summarizes the guiding principles of PD as follows:

1. equalizing power relations,
2. situation-based actions,
3. mutual learning,
4. tools and techniques,
5. alternative visions about technology, and
6. democratic practices.

Users are treated as experts in their own field, and they are supposed to bring their (tacit) knowledge and skills to the research and design process (Steen, 2011). Steen (2011) argues there are two tensions in human-centred design: first, there are different perspectives between researchers, designers, and users, and a gap between them; and second, there is a tension that concerns "what is" (the present) and "what could be" (the future). The researchers and designers cope with these tensions by critically reflecting on methods, roles, and the usage of power and agency in their projects (Steen, 2011). There is variation in how participation is conducted; the type of participation, and the type of participation methods and techniques (Halskov and Hansen, 2015). End-user participation in the design of new IT developments has been especially significant in promoting practical relations between work and technology, workplace democracy, and technological infrastructures serving both professionals and customer markets (Bjerknes and Bratteteig, 1995; Kensing and Blomberg, 1998). End-user participation results in increasing

knowledge, the development of realistic expectations, the reduction of resistance to change, and the provision of opportunities to participate in decisions that are likely to affect the end-users' work (Bjerknes and Bratteteig, 1995). Design teams consist of people with different backgrounds, experiences, and interests.

Co-design can be called the contemporary practice of PD using tools and techniques from other fields (Steen, 2011). Co-design involves designers and people not trained in design working together creatively in the design development process (Sanders and Stappers, 2008). Co-design is plotted more to the future (what could be) than PD (Steen, 2011). In space design and architecture teams, not all the participants have a background in design, but they do have experience in their own discipline (Sanders et al., 2010). Co-design teams will become more diverse in the future (Sanders and Stappers, 2008). Furthermore, architecture and planning are the latest of the traditional design disciplines to show an interest in exploring new design spaces, primarily in the design of healthcare environments (Sanders and Stappers, 2008).

Co-design allows end-users to stay in their own field of expertise, but end-users must be given the appropriate tools and techniques for expressing themselves (Sanders and Stappers, 2008). One of the major challenges in the planning and architectural design is the communication gap between design teams, various levels of end-user groups, and specialized consultants (Sanders and Stappers, 2008). The methods, tools, and techniques together with the mutual design language support and facilitate future co-design processes (Sanders and Stappers, 2008). The pre-design phase, also called the front end, involves many activities to inform and inspire considerations for forthcoming options (Sanders and Stappers, 2008). It is followed by the traditional design process with ideas, concepts, and prototypes (Sanders and Stappers, 2008). Low-fidelity VPs can be utilized earlier in the pre-design phase (fuzzy front end) in architecture to elaborate the size and shape of the space or the placement and necessity of furniture and equipment.

The margin between PD and co-design is a narrow one. Co-design is more future-orientated and the relationship between designers and users is more equal. Additionally, co-design has a growing emphasis on the front end (formerly pre-design) and new tools, techniques, and processes. In co-design, creating and evaluating prototypes can be seen as aiding focused discussions in a team and allowing the participants to experience a situation that has not existed before(Sanders and Stappers, 2014).

## 2.2 Virtual reality and virtual prototypes

The tools and techniques in PD and co-design range widely from tools that enable observation of participants and their work (workshops, fieldwork, surveys, interviews) to tools to support participation (scenarios, mock-ups, future workshops, design games, prototyping) (Kensing and Blomberg, 1998). Watkins et al. (2008) utilized physical mock-ups as "inter-active laboratory" environments with PD, mixed methods, and EBD solutions. Simulation and visualization enable participants to test and modify universal patient rooms and to contribute to the knowledge base of the healthcare design community (Watkins et al., 2008). In their study, Elf et al. (2016) used group-modelling in the predesign phase for new healthcare environments. The method supports healthcare participants in design teams to focus more on the healthcare organization and care activities rather than on layout solutions (Elf et al., 2016). Reay et al. (2017) have presented a case study of a co-design laboratory in a hospital where designers, students, patients, and hospital staff worked together to identify and address healthcare issues in an innovative way.

Visualization tools have evolved to design and shared digital material. New technology provides platforms range from desktop computer monitors with a 3D stereoscopic effect to true-stereo full-scale 3D platforms like walk-in VEs and head-mounted displays (HMD) (Kim et al., 2013). These visualization tools have been used in healthcare facility design. Earlier, the visualization tools were drawings, 3D pictures, and physical mock-ups, but lately there has been a change to VR tools (Kalantari and Neo, 2020). The transition to VR tools is still ongoing, but there are many issues to be studied about the VR platform, e.g. low- or high-fidelity and usability (Wingler et al., 2019; Wingler et al., 2020; Kalantari and Neo, 2020; Health Quality Council of Alberta, 2020; Joseph et al., 2020). VE and VR have been utilized in architecture and the design of new healthcare facilities with individual participants or groups designing various room types (Fröst and Warren, 2000; Dunston et al., 2007 and 2010; Persson et al., 2014; Wingler et al., 2020). Visualization tools and techniques promote a practice where the designers can learn from the participants' work, and where both technology and the work organization are the focus (Kensing and Blomberg, 1998). Visualization helps the participants take an active role in design. The number of these studies is growing, and interest and the actual utilization of PD, VR, and EBD methods is evolving, as shown in the series of investigations in healthcare design with interdisciplinary user groups (Carthey 2020a, 2020b, 2021).

In their review, Kim et al. (2013) classified 150 journal papers (2005–2011) in the field of the built environment concerning the use of VR and VE. Collaborative use of VR systems was presented in 36 articles (26%). The authors also predicted that multidisciplinary collaboration would become a standard in built environments (Kim et al., 2013). In their

review, only two articles used HMDs. Recently the number of VR studies in healthcare facility design have increased with the use of HMDs and case studies with individual users (Heydarian et al., 2015; Wingler et al., 2019; Wingler et al., 2020) and in simulation (Shultz and Rja, 2021). Collaborative participation and co-design with multiple participants exploring and interacting simultaneously are not available with HMDs as they are in walk-in type VEs (Joseph et al., 2020). There is only some research on the effectiveness of collaborative visualization in walk-in VEs, although collaborative sense-making is regarded as one of their essential benefits (Cordeil et al., 2017). Joseph et al. (2020) claim that immersive VEs are underutilized in the design of healthcare facilities. When designing healthcare facilities, one should recognize that the performance of healthcare is essentially a team-based activity that requires multiple people to be in a space and to dynamically react to the space and each other (Joseph et al., 2020). Relatively few environmental design studies have been conducted with immersive VEs within healthcare facilities prior to 2020, but there are a range of different VR applications with a level of visual and behavioural realism and capabilities for interaction and evaluation (Joseph et al., 2020).

CAVE technology has been used in the collaborative design of laboratory layouts (Fröst and Warren, 2000). The results show that CAVE provides users with a method that helps them to formulate, analyse, test, and realize their ideas (Fröst and Warren, 2000). Furthermore, a virtual mock-up of a patient room with interactive elements had been built where individual healthcare practitioners could perform a variety of actions, i.e. rearrange furniture, adjust lighting, and change the size of the room (Dunston et al., 2007 and 2010). Dunston et al. (2007 and 2010) have suggested using VR mock-ups instead of physical mock-ups because they are less expensive and easier to modify. Comparing "user-real product" and "user-virtual product" interaction individually and in focus groups using a participatory design approach, researchers claim that VR provides a tool to evaluate the usability of the virtual product interface and gives the end-users a communication channel to involve themselves directly in the design process as co-designers (Bruno and Muzzupappa, 2010). VR and VPs provide more development ideas for furniture compared to physical ones from non-technical consumers (Tiainen et al., 2014). Bullinger et al. (2010) have combined architecture, user-centred design, PD, and an immersive VE in their studies on designing a new laboratory building. The use of user-centred design with a VE increases quality, and performance in building and construction projects can be measured from an economic point of view by how well it meets future users' expectations (Bullinger et al., 2010).

An important issue is how the VP setting works in cases with multiple people, a scenario that is important in collaborative design. Collaborative visual analysis is important (Cordeil et al., 2017). For such needs, only a walk-in VE like CAVE works, as the participants see the same image (i.e., the same VP) and each other. Thus, they see what others are doing but also their nonverbal signs (gestures and expressions) during the session. CAVE has

advantages like multi-user possibilities, a wider field of view, and the physical presence of users (Vasconcelos et al., 2019). Furthermore, participants can maintain a better sense of spatial orientation as they can see their bodies (Ragan et al., 2016). Full-scale VPs can be evaluated by HMDs as a platform (Heydarian et al., 2015; Wingler et al., 2019; Wingler et al., 2020), but an HMD is impractical for collaborative evaluation, as the collaboration space is collocated and remote, and the participants are unable to see other users (Cordeil et al., 2017).

When using VPs, the level of fidelity for prototypes needs to be decided. High-fidelity prototypes look like the final products with a large amount of detail, whereas low-fidelity prototypes are insufficient, like sketches and VPs without texture or other details, for example. There are opposite views as to what level of fidelity works best in user evaluation. On the one hand, high-fidelity prototypes help professionals, and even non-professional participants, perform accurate design reviews (De Casenave and Lugo, 2018). On the other hand, when low-fidelity prototypes are used, the non-technical users have more space to evaluate and develop the presented prototypes (Davies, 2004; Yang, 2005; Tiainen et al., 2014).

VPs offer a new platform for discussing prospective use and possible improvements. VPs use computers to visualize the prototype, but there is variation in terms of how realistic the visual image is. In addition to visual images, VPs might also include some functions of the product. The benefit of using VPs is that they reveal more development ideas compared to physical prototypes (Tiainen et al., 2014). Additionally, immersive VPs have the potential to increase the quality of reviews and decrease the cost and duration of the design process (De Casenave and Lugo, 2018). Additionally, VPs are easy to modify, so new ideas can be quickly incorporated, and new versions can be evaluated (Tiainen et al., 2014; Kalantari and Neo, 2020).

Physical mock-ups have been used, and they are still in use when designing healthcare facilities, but there is an ongoing transition to virtual mock-ups. Physical and virtual mock-ups have many mutual features. They can be used to design spaces and to provide simulations. They can be of varying levels of detail, they provide immersion, and they can be evaluated in groups or individually. Furthermore, changes in both mock-ups can be costly and time-consuming (Watkins et al., 2008). VR technology has evolved thanks to 3D architectural applications, building information models, and game engines, and changes can be made rapidly and at a lower cost. Another advantage of VR is that it allows one to design larger spaces than just a few rooms, thus providing larger layouts of facilities for evaluation (Tutt and Harty, 2013). Additionally, with VPs one has multiple options to compare and evaluate (Durham and Kenyon, 2019; Wingler et al., 2020). VR mock-ups can be stored digitally and be used and evolved in other design processes (Durham and Kenyon, 2019). Shultz and Rja (2021) have collated the advantages of using VR mock-

ups: enhanced ability to visualize design challenges and solutions, simultaneous examination of multiple design options, decreased costs and time, and optimized quality and safety as a part of the healthcare facility design process. Moreover, they have found that the use of VR to conduct a simulation-based mock-up evaluations of a healthcare facility can produce a positive and substantial return on investment.

## 2.3 Evidence-based design

Healthcare facility design is a process where multiple diverse stakeholders take part in decision-making, and there are many objectives – operational, environmental, experiential, and organizational – to accomplish (Halawa et al., 2020). Healthcare facilities today are more technological than earlier, and technological integration and layout design should enable fluent processes for patient care and assist healthcare professionals (Bayramzadeh and Aghaei, 2021). EBD is a multi-discipline orientation to study and analyse design and operational processes in healthcare in order to learn best practices and find scientific proofs for design solutions (Ulrich et al., 2008). The aim is designing better and safer hospitals. Empirical studies link the design of the hospital's physical environments and healthcare outcomes. Results of studies are organized according to three general types of outcomes: patient safety, other patient outcomes, and staff outcomes (Ulrich et al., 2008). Patient safety includes infections, medical errors, and falls (Ulrich et al., 2008). Other patient outcomes include issues such as pain, sleep, stress, depression, length of stay, spatial orientation, privacy, communication, social support, and overall patient satisfaction (Ulrich et al., 2008). The scientific research relevant to staff outcomes surveys issues such as injuries, stress, work effectiveness, satisfaction, and recruitment (Ulrich et al., 2008; Rechel et al., 2009; Steinke et al., 2010). Sustainability has additionally been investigated recently as a part of EBD outcomes (Brambilla and Capolongo, 2019).

As the opportunities to participate in the design of healthcare facilities have increased for healthcare professionals, they need information on the best practices and studies of healthcare facility design. EBD has expanded as an important source of information in the design of healthcare facilities, and healthcare professionals need some knowledge of EBD when participating in the design process (Ulrich et al., 2008; Cesario, 2009; Redden and Evans, 2014; Sundberg et al., 2017; Anåker et al., 2017). The participation of healthcare professionals in design should start from the initial design stage (Rechel et al., 2009), and participants should represent different hospital occupations, because they all have different spatial needs when working (Rechel et al., 2009; Redden and Evans, 2014; Lavander et al., 2015; Lavender et al., 2020). The participation of nurses is especially important due to their number relative to all other occupations, their direct daily activities with patients, and the layout of the facility affecting their workflows and processes (Clark, 2014; Redden and Evans, 2014; Sundberg et al., 2017).

One way to study the success of a design is to conduct a POE. POE is defined as "the systematic evaluation of health service buildings or facilities assumed to occur sometime after their occupation and usually defined period of use such as 12 months to 2 years" (Carthey, 2006, p. 58). The POE has been poorly utilized in the evaluation of healthcare facilities, even though it provides results generating new knowledge about the human use of space and provides feedback on the key decisions made during the design and construction process (Vischer, 2009). The number of studies and reviews indicates a growing interest in the topic (Göçer et al., 2015; Li et al., 2018; Brambilla and Capolongo, 2019). There are considerable differences between countries in developing and conducting POEs. According to recent reviews, there were almost 20 POE protocols and numerous other case-related tools and methods with diverse purposes of use (Li et al., 2018; Brambilla and Capolongo, 2019). Using Ulrich's EBD framework and 13 POE instruments, Brambilla and Capolongo (2019) analysed how those tools test health, sustainability, or both. POE methods include subjective methods – like occupant surveys, interviews, walkthroughs, focus groups – physical measurements – like energy, electricity, water, and indoor environmental quality (thermal conditions, lighting, indoor air quality, and acoustics), and audits (Göçer et al., 2015; Li et al., 2018). Furthermore, pre- and post-occupancy evaluations have been studied to investigate the outcomes of indoor environmental quality (Bae and Martin, 2023). The most frequently used method is a survey to evaluate end-user satisfaction. Petäjä et al. (2025) have studied POE results in relation to work engagement, and they argue when designing physical work environments that attention should be paid to safety, security, and comfort features, as they may impact work engagement.

When evaluating healthcare facilities, the focus has shifted more onto EBD variables and outcomes (Brambilla and Capolongo, 2019). Earlier studies emphasized patient health and well-being (Codinhoto et al., 2009), while the health and performance of the staff and sustainability have additionally been investigated recently (Brambilla and Capolongo, 2019). The scope of POE studies and protocols is comprehensive, and a great variety of variables are examined. The role of stakeholders in the design and building process has increased, especially in the healthcare field, and stakeholders' expectations and needs vary. When including POE in the design and building process, it is possible to bridge the gap between design intent and the actual performance of the building with better information and knowledge (Göçer et al., 2015).

Furthermore, it is useful to set targets to help measure the success of the design (Vischer, 2009; Pati and Pati, 2013; Schreuder et al., 2015). Elf et al. (2015) have criticized POEs that focus more on the experiences and opinions of end-users rather than on predetermined quality criteria. It is recommended that commitments are made to pre-design evaluation and POE (Kotzer et al., 2011; Guinther et al., 2014; Alvaro et al., 2015). POEs have been conducted as research instead of part of the design and construction

process to ensure continuous improvement (Elf et al., 2015). Pre-design evaluation and POE studies emphasize the importance of checking the performance of the designed layout by analysing the results with criteria and deviations (Kotzer et al., 2011; Halawa et al., 2020). Additionally, Schreuder et al. (2015) found that healthcare staff need assistance with technical issues after commissioning and occupation.

While the use of POEs has increased, there are several barriers that prevent POEs from being an essential part of design and construction practice (Guinther et al., 2014). Barriers include issues like the cost and time needed for POEs, a lack of research expertise, and an unwillingness to expose problems and failures (Guinther et al., 2014). Healthcare professionals also lack the knowledge to request a POE, and, as the methods and variables are numerous, it is difficult to know what method to use to achieve the goals.

The present situation in the design of healthcare facilities concerning participation and evaluation in Finland is quite like that described of the international situation above, but virtual visualization tools are at present quite frequently used in the design of Finnish hospitals when designing new buildings. EBD is known marginally, and there are only a few Finnish EBD studies to introduce the research methods and available results to the design of new healthcare facilities and their evaluation (Valkeisenmäki, 2020; Seppälä, 2023). Valkeisenmäki (2020) has studied knowledge of and the actual use of EBD in Finnish hospital districts, and the results of expert interviews show that EBD is not utilized to its potential in Finland. In her master's thesis, Seppälä (2023) aimed to promote the systematic evaluation of healthcare buildings in Finland with a standardized POE occupant questionnaire for social and healthcare staff.

# 3 RESEARCH METHODS

In this chapter, the three sequential CAVE cases are presented from a methodological perspective. The aim of these cases was to find and study new approaches to enable more user-orientated healthcare facility design (Nykänen et al., 2008). As the used methods and tools were new, it was relevant to study the utilization of VR tools and experience by users both as individuals and groups. Additionally, we sought to determine if the use of these methods and tools have any impact on the design outcome or end-user satisfaction. All these cases had a background in actual hospital design projects, and the participants had a strong commitment in participating. The two first cases supported the design of a new hospital building, and the third case included all the phases of design, construction, and POE in the research plan for a new intensive care unit. All three projects participated in and received funding from the programs of Tekes (the Finnish Funding Agency for Innovations), and they involved several partners from research institutes, hospital districts, designers, companies, and universities of applied sciences (Nykänen et al., 2008; Yli-Karhu et al., 2011; Nykänen et al., 2016). The names and times of the projects, the role of the PhD candidate in the project, the project's role in the PhD process, the number of participants, and the articles are compiled in Table 1.

Table 1. The three cases relating to this dissertation.

| Number of cases | CASE 1 | CASE 2 | CASE 3 |
|---|---|---|---|
| Name of project | HospiTool | HospicaseY | Evicures |
| Time of project | 2006–2008 | 2009–2011 | 2014–2016 |
| PhD candidate's role in the project | VE visitor's interviewer (nurses)<br>Member of the project board<br>MSc (IT) June 2008 | Researcher<br>Project manager | Researcher<br>Member of the project board |
| Projects' role in the PhD process | Understanding how individuals can evaluate VPs, and which features can be evaluated reliably. Comparison VPs with physical patient rooms. | Understanding how groups can visit VR and evaluate VPs. Studying collaboration of participants. Developing a questionnaire for POE and conducting a POE in 2013. | Co-design of healthcare facility with multi-occupational groups and architect. Conducting a pre-design evaluation and a post-occupancy evaluation. Setting predetermined quality criteria for design. |
| Participants in the empirical study | 11 patients<br>11 nurses | 280 participants<br>50 groups | 238 participants<br>47 groups |
| Articles | Article 1 (2010) | Article 2 (2014) | Article 3 (2019)<br>Article 4 (2021)<br>Article 5 (2022) |

The PhD process of the researcher started with the writing process of the first article in 2009. From the beginning of the second case, the researcher's role was organizing and participating in CAVE visits with multi-occupational groups, analysing the results of questionnaires with the project group, and developing a questionnaire for post-occupancy evaluation with other researchers. The researcher conducted the post-occupancy evaluation in autumn 2013 and wrote the second article. The planning of the third case started right after the end of the second case. The researcher conducted the pre-design evaluation in spring 2014 and compiled the predetermined design criteria for the intensive care unit in spring 2014 before the third case. In spring 2015, the researcher participated in co-designing with multi-occupational groups in CAVE in three iterative cycles. The researcher participated in all of them and analysed the results of the questionnaires with SPSS software. The researcher participated in the design, construction, and occupation of the new intensive care unit in 2016–2018. The post-occupancy evaluation was conducted in autumn 2019. The results of the POE were introduced to the staff in spring 2020. The statistical comparison of the cases was conducted in 2020 and 2024. Articles 3, 4 and 5 were written in 2018–2021. The studies at Tampere University were carried out in 2014–2021. The writing of dissertation started in 2021 and ended in August 2025.

## 3.1 Research methods selection

Case studies and action research were chosen for methods in seeking the answers for research questions providing close connection with participants. By examining and synthesizing the methods and tools employed by other researchers across all phases of design, construction, occupancy, and evaluation, we obtained insights that both corroborate previous findings and reveal new information made possible through longitudinal studies and comparative analyses of pre- and post-evaluation conditions. Additionally, the evaluation of the tool and methods used in the design can be augmented with end-user satisfaction and design outcome.

As collaborative design, virtual technology and EBD support end-user participation in design and there are many studies utilizing these methods and tools. Many studies have explored the suitability of VPs, but they have not been used in actual design and construction projects (Dunston 2007; Wingler, 2020). Also, in some studies the participants have been individual students, not experienced healthcare professionals (Mc Laughlan and Liddicoat, 2018; Wingler, 2020). Only a few studies have been collaborative (Fröst and Warren, 2000; Mobach et al., 2008; Bullinger et al., 2010; Tutt and Harty, 2013; Persson et al., 2014; Maftei and Harty, 2015) just like the latter two cases of this dissertation. Moreover, staff have not had the opportunity to participate in the design in cases where a pre-design evaluation or a POE has been conducted (Berry and Parish,

2003; Kotzer, 2011; Ferri et al., 2015; Alvaro et al., 2016). Additionally, when conducting POEs, researchers focus on the experiences and opinions of users rather than fulfilled predetermined quality criteria (Elf et al., 2015; Alzimer et al., 2019). In this dissertation, the whole chain is investigated, from utilizing VR and VPs, co-design, EBD, pre-design evaluation, predetermined quality criteria, to POE. The third case fills the research gap by providing results from whole chain of design, construction, occupation, and evaluation. Table 2 shows the studies using two or more of the above-mentioned elements.

Table 2. Corresponding studies with multiple methods and tools.

| | Collaborative design | | Virtual technology | | Evidence-based design | | |
|---|---|---|---|---|---|---|---|
| STUDY/ USED METHODS | PD | Co-design | VR | VP | PDE | PQC | POE |
| Fröst & Warren, 2000 | x | | CAVE | x | | | |
| Berry & Parish, 2003 | | | | | x | | x |
| Dunston et al., 2007 | | | CAVE | x | | | |
| Mobach, 2008 | x | | Cylindrical screen | x | | | |
| Bullinger et al., 2010 | x | | Projection based screen | x | | | |
| Kotzer, 2011 | | | | | x | x | x |
| Tutt & Harty, 2013 | x | | CAVE | x | | | |
| Maftei & Harty, 2015 | x | | CAVE | x | | | |
| Persson et al., 2015 | x | | EON Icube | x | | | |
| Alvaro et al., 2016 | | | | | x | | x |
| Fay et al., 2017 | x | | | | | | x |
| Alzimer et al., 2019 | | | | | | x | x |
| Durham & Kenyon, 2019 | x | | Projected computer screen (3D) | x | | | |
| McLaughlan & Liddicoat, 2019 | | | HMD | x | | | |
| Wingler et al., 2020 | | | HMD | x | | | |
| Shultz & Jha, 2021 | | | HMD speaker, microphone | x | | | x |

(PDE pre-design evaluation; PQC predetermined quality criteria)

## 3.2 Research methods of cases

In this dissertation, the three cases form a continuum of utilizing collaborative design with CAVE. The studies started with an analysis of which features can be reliably evaluated in CAVE and what features the participants bring up in CAVE. CAVE was tested both with individual participants and with multi-occupational groups. In these three cases, we used multiple methods and tools to gather the results of studies, and all the CAVE visits were video-taped and transcribed verbatim.

The research method of the first two studies was a case study. A case study is a social science research method investigating a contemporary phenomenon in depth (Yin, 2018). As the cases were experimental at the beginning, the case study method was applicable. These cases were bounded, and phenomena were studied in a real context using interviews, questionnaires and observation for data collection (Verne and Bratteteig, 2018). The objectives of the research were to ascertain which features can be reliably evaluated in CAVE and how the participants described their experience. The cases were single-case studies, as they were separate and consecutive. The results of each case impacted the direction of the following case. The first case was qualitative, and the following cases used mixed methods. The data were collected from different sources, and mixed methods with statistical analysis were used in the latter two cases.

The third case was action research. In IT, methodologies were quantitatively orientated up until the mid-1990s (Sarker et al., 2013). The methods with qualitative approaches used in other sciences have gradually taken root beside quantitative research in IT. One qualitative approach is action research, which emphasizes collaboration between researchers and practitioners in studies of organizational or functional changes (Avison et al., 2001). Action research can be defined as "An iterative process involving researchers and practitioners acting together on a particular cycle of activities, including problem diagnostics, action intervention, and reflective learning" (Avison et al., 1999, p. 94). In action research, the iterative research process capitalizes on learning by both researchers and practitioners in the context of an organizational or functional change (Baskerville and Myers, 2004). Researchers bring their theoretical knowledge and practitioners bring their situated, practical knowledge (Baskerville and Myers, 2004). The purpose of action research is to gain a shared understanding of a complex organizational problem with various stakeholders in real time (Avison et al., 2018). Action research differs from a case study approach in terms of the role of the researcher. In a case study, the researcher can observe and comment without being personally involved, whereas in action research, the researcher collaborates with practitioners, is involved in the actual change process, and shares both practical and scholarly knowledge (Avison et al., 2018). Though the methods

for data collection are the same as in case studies, the aims are different; action research aims to plan the change and evaluate the results as they occur (Verne and Bratteteig, 2018).

The underlying philosophy of action research is pragmatism, as it concentrates on asking the right questions and getting empirical answers to those questions (Baskerville et al., 2004). To ensure the right questions are asked, action research should be defined thoroughly regarding the premises, purpose, practical actions, and collaborative problem solving and reasoning.

Action research was feasible for this case because of the enormous change that would occur in the work of nurses and other healthcare professionals when commissioning single-patient rooms in an intensive care unit for the first time in Finland. The change would concern collaboration, communication, and processes in care. In the design process of the new premises, the knowledge and experience of participants concerning the needed spaces and operational processes were essential. The knowledge and experience of participants was needed to design the single-patient room in terms of form, space, furniture, and accessories to be most practical and convenient to meet the requirements of care. The rooms were designed to be identical and similarly equipped to diminish seeking and walking. The design of the rooms was performed iteratively in three cycles.

In this action research mixed methods were used. With the use of quantitative methods (questionnaires), the results of the qualitative methods (interviews) could be confirmed. In the case, the forthcoming change was examined from the viewpoint of the participants as action research. Co-design with VPs enabled the participants' more equal participation and contribution to the design by evaluating the VPs and describing their workflows. As they work in social interaction in multi-occupational groups, they shared their knowledge, skills, and opinions with other participants representing other occupations.

The iterative operations model of the action research was performed in the following way during the pre-design phase. The architect designed low-fidelity VPs of rooms, which were presented to the multi-occupational groups for analysis and suggestions for changes (problem diagnostics). The changes were justified by the need for space or the usual workflow. Afterwards, the research group including representatives from intensive care unit analysed and evaluated the proposed requests for changes and decided which of them were to be put forward to the next VPs (action intervention). The requests for changes were collected from discussions, questionnaires, and the researcher's notes. Reflective learning occurs when participating in CAVE with multi-occupational group and discussing needs for functional workflow and workplace. Additionally, reflective learning occurs when evaluating the changes made for next VP. There were three iterative cycles, and the final designs of the rooms were used in the architectural design.

The participants of the action research completed three questionnaires. The first was the pre-design evaluation (2014) in which the staff evaluated the facilities and functions of the old intensive care unit. During the pre-design phase in CAVE (2015), participants filled a questionnaire to evaluate the qualities of VPs and collaborative design in CAVE. The last questionnaire was the POE (2019) evaluating the new intensive care unit, and the results were contrasted with the pre-design evaluation results. The POE results were also compared to contrast the evaluations of the participants involved in the pre-design phase with those who did not participate in the pre-design phase.

The ethical principles in these cases were similarly organized. First, no identified personal data were gathered, and participation was voluntary. The information included age or age group, sex, occupation, and working experience in years. Second, the participation was voluntary, and participants could withdraw from the CAVE visit any time. The participants signed an informed consent form, and the forms were documented by VTT Technical Research Centre of Finland. Third, all individual participants and multi-occupational groups received information beforehand, including on CAVE and the research objectives. The discussions in CAVE were transcribed verbatim and in these documents no names were mentioned.

## 3.3 The hospital and three cases

The hospital participating in these cases was the Central Hospital of Seinäjoki, situated in the County of South Ostrobothnia in Finland. The hospital provides specialized medical care for almost 200,000 inhabitants of the county.

In the two first cases (HospiTool and HospicaseY), the aim was to assist and facilitate the design of a new hospital building, "Y-talo", on the hospital campus. The new hospital building has a floorspace of 33,870m$^2$ with 1,400 rooms, 134 patient beds, and 20 different hospital units. Part of the new hospital was occupied by the primary healthcare services of the City of Seinäjoki (Article 2). The patient rooms with a bathroom for the new hospital building were compared with patient room models from Sweden and the USA (Article 1). As the new hospital building has outpatient units, a consulting room was modelled as a VP for evaluation. The new emergency centre with new patient flow and other functionalities was modelled virtually on a larger scale (1,000m$^2$) to evaluate the routes, visibility, and functionality. During the design phase in CAVE, some 20 proposals for changes to the location of equipment and furniture, height of windows, colours, etc., were accepted, which multiplies up to 100 patient rooms and 100 consultation rooms. The changes were minor in scale, but important from a functional stance, as the construction was ongoing (Article 2).

The third case (Evicures) provides a real process of the design, construction, and evaluation of an intensive care unit utilizing the methods and tools used in the two previous cases, adding the pre-design evaluation and predetermined quality criteria. The third case permitted the participation of healthcare professionals in all the design, construction, and evaluation phases. The new intensive care unit has only single-patient rooms, which was a novelty for intensive care units in Finnish healthcare. Additionally, the new intensive care unit merged all intensive and intermediate care into one unit. The participation of healthcare professionals was highly important to benefit from their experience and expertise in the design and function (Article 5).

## 3.4 Platform of virtual reality in the cases

In all these three cases, the scenery was CAVE, situated in the Virtual laboratory at the University of Applied Sciences of Seinäjoki, Finland. This site was the only CAVE in Finland during the time of the cases. The Virtual laboratory had been a scene for several VR projects and studies. CAVE was established in 2005, and it was new and well equipped (Nykänen et al., 2016).

CAVE is a room comprising three walls, a ceiling, and a floor. The fourth wall is open to allow access into the space. The walls are each 3 x 2.4 metres. The floor space is 9m². Images generated using a computer system were projected onto these surfaces, which were transformed into a three-dimensional full-scale environment when viewed through stereoscopic glasses (Figure 3.). The most important property of CAVE is its full scale, allowing visitors to perceive the environment as almost real. A single visitor wears stereoscopic glasses that track the viewer's position and orientation. Stereoscopy provides the third dimension – depth. With several visitors, the group should stay near the visitor with the 3D tracking glasses to have an optimal view or change the user of the 3D tracking glasses during the visit. The visualization software renders the stereoscopic image on each display wall of CAVE, synchronously and properly skewed according to the perspective of the viewer's position and orientation. Visitors can move to some extent within the space itself, and travel longer distances with the help of a 3D mouse. The software used in these cases was TreeC Technology's VR4MAX (Nykänen et al., 2016).

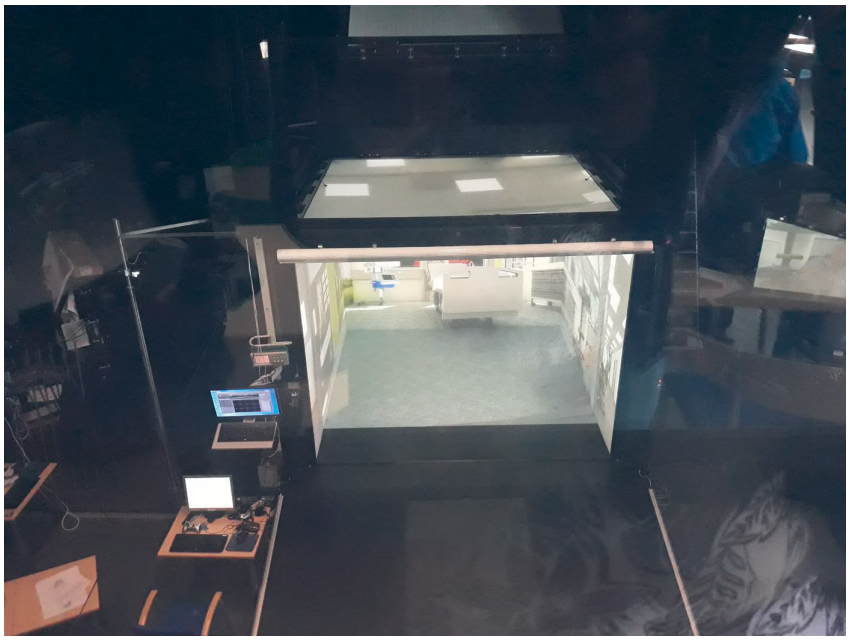

Figure 2. This is the CAVE used in these studies. In front is the entrance to CAVE and there are images on five surfaces, which form a 3D full-scale environment when viewed though stereoscopic glasses. The surrounding of space is dark including hardware like computers and projectors. Photo: Tiina Jouppila

## 3.5 Case 1: HospiTool

The first case was "A User-oriented Hospital Space" (HospiTool in 2006–2008) and the aim was to find new approaches to enable more user-oriented healthcare facility planning. The goal was to provide tools for end-user participation and to set the requirements for the design, use, and maintenance of the building. In this case, the aim was to discover what features can be reliably evaluated in CAVE and how the participants describe their experience. The participants were patients (11) and nurses (11): half of both participant groups evaluated the physical patient rooms in their wards and half of them had individual CAVE visits where they evaluated four different patient rooms.

The patient rooms were selected for evaluation for several reasons. First, patients spend more time in patient rooms than in other hospital premises. Second, almost one third of the hospital premises consists of patient wards, although the number of patient beds being reduced. Third, the patient rooms as a working environment influence the staff's fluency of working, job satisfaction, ergonomics, and stability, which are important factors in the future when the competition for workforce increases. Four different patient rooms with

bathrooms were modelled for CAVE. Two patient rooms were models from the USA and Sweden, and the other two designs were of a single-patient room and a double patient room of a forthcoming hospital building for Y-talo. EBD features were applied in the design of those patient rooms (Nykänen et al., 2008).

The first case of this dissertation was qualitative, collecting individual end-user opinion data for evaluating the VR systems. In this case, the features of the VPs were examined to determine whether they could be assessed reliably in CAVE. The features were contrasted with the results for physical rooms in a hospital. The end-users' views were gathered with semi-structured interviews, as was done by Douglas and Douglas (2004). There were features that cannot be evaluated, like temperature, air conditioning, and surface materials. There were also features that could be evaluated only with limitations, like room size, mobility, or lighting. Some features were not included in the VR model used, like noise. To contrast with the physical hospital environment, some of the interviews were conducted in three separate hospital wards where the patients were receiving care. The evaluation of physical and virtual rooms in semi-structured interviews included such features as

- colours,
- lighting,
- placement of furniture,
- space,
- surface material,
- a view from the window,
- comfort,
- practicality, and
- aesthetics.

Also, the participants were asked which features they liked or disliked in the physical and virtual rooms, and how they experienced the evaluation in CAVE. The participants were able to evaluate the features of virtual rooms in detail, and they felt they could imagine how the complete room would look. The evaluation of sizes and heights caused uncertainties for patients and nurses, as did evaluating the right size of space needed for helping patients. The participants found the virtual rooms immersive and had a positive stance towards CAVE itself. All the nurses perceived CAVE as a useful tool for designing hospital environments (Nykänen et al., 2008; Article 1).

## 3.6 Case 2: HospicaseY

The affirmative results of the HospiTool case led to the second case, HospicaseY (2009–2011), where the use of CAVE changed to be collaborative with end-users and designers.

The collaborative notion used in this case involves the simultaneous participation of multiple healthcare professionals in CAVE designing together with the architect. The methods and tools in this case were CAVE, VPs, collaboration with other participants and the architect, EBD, and a compiled POE questionnaire from the results of this case and the EBD literature. In CAVE, there was no chosen method for collaboration. The architect introduced the visited rooms and their purpose. Conversations were lively, though sometimes questions from the architect were needed (Yli-Karhu et al., 2011). Instead of using individual participants, this case introduced the attendance of multi-occupational groups, and they evaluated VPs of a patient room, bathroom, consultation room, and over 1000m² of emergency centre facilities for a forthcoming hospital. These VPs were high-fidelity. The aim of the case was to have 50 participants attending CAVE, but ultimately there were 34 groups (the group size varied from 2 to 10 participants, on average 4–6 participants) and 280 participants altogether, of whom 158 completed the feedback questionnaire. As the participants were from units that were going to move to this new hospital, they naturally formed multi-occupational groups (physicians, nurses of various levels, physiotherapists, secretaries, cleaners, etc.).

In this case, the objects were discussion topics in CAVE and the feedback questionnaire of the visit regarding the first impression, space, furniture and accessories, colours and lighting, functionality, comfort, and VE itself. The feedback questionnaires were analysed with SPSS and the discussions were recorded, transcribed verbatim, and analysed qualitatively with Atlas.ti. There were 14 main themes, and 26 sub-themes identified from 4600 comments made by the participants during the discussions. It shows that CAVE as a visualization tool and in collaboration with others enable participants to discuss and comment on various features concerning healthcare facilities. It was possible to experience most of the themes in CAVE, but not all, such as acoustics or opening windows (Yli-Karhu et al., 2011).

The questionnaire feedback on CAVE experience proved to be positive, although only minor changes could be executed to these VPs as the construction was ongoing.

With results of this case and together with the EBD literature, a POE questionnaire was compiled to be used from 12 to 24 months after a handover of the healthcare facility. The questionnaire consisted of background data and 106 statements on nine different topics (Yli-Karhu et al., 2011):

1. yards and entrances,
2. architecture,
3. indoor conditions,
4. durability,
5. functionality,
6. safety,

7. comfort,
8. accessibility, and
9. usability.

This POE questionnaire was utilized in the autumn of 2013 for the first time. There were 182 staff members who completed the questionnaire. The response rate was 40%.
The results were calculated with SPSS software. A thorough statistical analysis was done retrospectively after the statistical results of the Evicures POE were calculated. As the percentage values of CAVE visitors was at a slightly higher level in HospicaseY, the interest in inspecting the impact of participation statistically was also aroused in this case. The findings aligned with Evicures.

## 3.7 Case 3: Evicures

The third case was Evicures (2014–2016), but part of the studies in this dissertation took place before and after the project-funding period. The design of the new intensive care unit (ICU) at Seinäjoki Central Hospital was launched in the pre-design phase in spring 2015. This involved co-designing with the healthcare professionals a single-patient room, a bathroom, and a nurse's charting station with the help of VPs. Predetermined quality criteria were set in autumn 2014 for the design and a pre-design evaluation was conducted in spring 2014 to evaluate the present intensive care unit. EBD research and best practices were utilized in the criteria compilation and in forming the topics and statements for the POE, which was used also in the pre-design evaluation to be able to compare the results. Evicures includes several other studies, which are introduced in the project report (Nykänen et al., 2016). In this dissertation, only PD, co-design, VR, VPs and EBD with the methods and tools they provided are investigated more closely. The POE was conducted in autumn 2019.

### 3.7.1 Study process of the Evicures

In this section, the timeline for design and evaluation is presented (Table 3). The interest to study a real design case for a healthcare facility arose during the former HospicaseY. The subject of an action research was an intensive care unit that had waited for renovation for some years. The management of the hospital had become familiar with EBD through the HospicaseY conference in 2011. The intensive care unit upgraded its functional plan (design brief) as the intensive care unit was to be placed elsewhere in the hospital instead of renovating the old intensive care unit. A research plan was prepared by the preliminary research group and the search for partners was ongoing. After those phases, a financing application was sent to Tekes. The funding was verified after some amendments to the application and negotiations with Tekes in 2014, and the Evicures case started. The action

research comprises several phases, which are presented in the following sections. The final architectural design and construction are excluded from this dissertation as those phases were not part of Evicures project. Table 3 shows the timetable of the design, construction, and evaluation.

Table 3. Timeline of design, construction, and evaluation.

| Year | Evicures |
|---|---|
| 2014 spring | Pre-design evaluation |
| 2014 autumn | Predetermined quality criteria |
| 2015 spring | Co-design with virtual prototypes |
| 2015 autumn | Design |
| 2016 spring | Design |
| 2016 autumn | Construction |
| 2017 | Construction |
| 2018 spring | Occupation |
| 2019 autumn | Post-occupancy evaluation |

### 3.7.2 Pre-design evaluation and predetermined quality criteria

A pre-design evaluation of the existing facilities of the intensive care unit was conducted in April 2014 before the actual action research was launched. The results of pre-design evaluation would be compared with results of the POE to distinguish possible changes in end-user satisfaction. The purpose was to evaluate the spatial properties of the old intensive care unit and ensure that features requiring improvement would be considered in the design of the new facilities. The pre-design evaluation was executed by an online survey, and invitations to participate were sent by e-mail. The survey included 13 topics with 116 statements to answer, and there was also space for open-ended questions. The features that needed the most improvement according to the pre-design evaluation were privacy, lighting, indoor air, and acoustics.

As the basis for the new intensive care unit, the predetermined quality criteria were formed from the principles of EBD studies. The clinical planning for the design gathered the predetermined quality criteria for the new intensive care unit to support the healing and well-being of patients and the well-being and performance of staff. These predetermined quality criteria were compiled from EBD studies, literature, and recommendations for intensive care facilities (Rashid, 2014; Redden and Evans, 2014, Thompson et al., 2012; Ulrich et al., 2008). The predetermined quality criteria were:

- single-patient rooms,
- optimal visibility,

- natural light and windows,
- privacy,
- effective lighting,
- pleasant acoustics,
- patient lifts,
- adequate space around the bed,
- the implementation of required hand hygiene,
- standardized patient rooms, and
- grouping of the patient rooms.

These predetermined quality criteria above were included in the clinical planning, and they were forwarded to the actual architecture design.

### 3.7.3 Co-design with virtual prototypes

Co-design was chosen as the collaborative method in CAVE. The reason was the iterative process with low-fidelity VPs. The task of the participants was to evolve the single-patient rooms, bathrooms, and nurses' station for a new intensive care unit with their occupational expertise and experience. The single-patient room VP had only a bed and ceiling-mounted booms in the first and second iterative cycles. As the evolution started from sizing and shaping the patient room and adding and locating furniture, equipment, and accessories, the co-design method supported better the cooperation between the architects and healthcare professionals (Article 4).

- The process of action research with VPs had a thorough plan, tasks, and timetable, and all the phases had a detailed description to follow. The distribution of assignments in the research group was the following: The architect designed and presented the VPs and answered technical and design questions.
- The navigator guided the viewing of VPs and used the 3D mouse.
- The researcher opened the conversation if needed, asked for details and grounds for changes, and defined comments.
- The nurse from the intensive care unit answered functional questions of intensive care unit.
- The photographer took videos and photos.

The researcher has a nursing background (midwifery) and an MSc in IT (2008). The researcher had worked as a midwife until 2004 and on healthcare facility projects from 2004. This background aided in understanding change proposals and the grounds for them, and it also enabled the researcher to explain why some technical solutions were not possible.

A project worker (nurse) from the intensive care unit organized the participants into groups of 4–6 people according to the working shifts of the nurses and the interest of other participating stakeholders from other hospital districts. The groups were multi-occupational, but there was at least one nurse in every group. The participants had not previously participated in designing healthcare facilities, and this was their first experience of CAVE. Participation was voluntary. In addition, information pertaining to the videotaping, photographing, and recording of the visits was provided and written consent was obtained from the participants.

The CAVE visits ran according to the design process plan in three iterative cycles. Each cycle had the same processes because there were always new participants in the groups. The participants received information in advance about CAVE, the location of the virtual laboratory, and the length and the purpose of the visit. They were told that the design of rooms would be in three iterative cycles and modifications would be made after feedback of participants. The participants were informed that the rooms were incomplete and that all comments and adjustments were more than welcome to motivate the participants to offer unusual proposals.

Before the design session in CAVE, the researcher introduced the case group, demonstrated how the work in practice would take place in CAVE, and explained the outline of the CAVE presentation. The participants were told that they could interrupt and comment at any time during the presentation. All the visits to CAVE were videotaped – first the rounds in VPs and later the discussions after the rounds. The participants completed a questionnaire in which they could evaluate the details of the VPs and the experience of designing in a multi-occupational group.

The research group had planned the route for the CAVE presentation. The spaces were presented in the following order: the intensive care room and the bathroom, the nurses' station, and the intermediate care room and the bathroom. The architect presented the spaces with the same description to all the groups. The planned tour took approximately 15 minutes. The groups could then return to the VPs they wished to evaluate in depth, and again the participants could interrupt and ask for details or comment at any point. The visit to the virtual rooms lasted 30–40 minutes.

After the presentation, the participants completed a questionnaire in which they could analyse the features of the spaces more systematically and evaluate the VPs and collaborative design experience. The purpose of the questionnaire was to make sure that all comments and evaluations would be brought together. A lively exchange of views usually followed where, in addition to talk about the spaces, the discussions involved different functions, changes in functions, and the number of needed healthcare professionals. Overall, the visits lasted one hour. After each cycle, the modifications to

the rooms were executed in accordance with the feedback. As the VPs were at the beginning low-fidelity, the participants could influence the size and form of the rooms, the placement of needed furniture and equipment, and many functional and safety issues (e.g. windows, doors, and visibility), justifying changes due to functional and practical needs (articles 3 and 4). The third VP of a single-patient room, which was forwarded to architectural planning, can be seen in Figure 3, and the implemented patient room is shown in Figure 4. Figure 3 shows the level of accuracy the VP had when the participants accepted the third VP. In Figure 4, the single-patient room is fully equipped and shows the need for space around the bed and the needed equipment.

Figure 3. The third VP of a single-patient room in a two-dimensional form. Photo: Tiina Jouppila

Figure 4. The implemented single-patient room after construction and commission. Photo: Samuel Hoisko

The total number of visitors to CAVE was 238. There were altogether 47 multi-occupational groups in three iteration cycles. The nurses numbered 160 (67% of all the participants), making them the largest occupational group. The other participant groups were physicians, designers, cleaners, technicians, healthcare and facility managers, students, and individual healthcare workers, such as physiotherapists. The percentages of other participant groups varied from 7% to 0.5%. The visits to CAVE took place in the spring of 2015. One third of the participants took part more than once

### 3.7.4 Post-occupancy evaluation

Very few – perhaps even zero – studies of healthcare facility design are conducted in a manner that enables the healthcare professionals to participate in the pre-design evaluation, the design, and the POE. In this action research, healthcare professionals took part in the design in CAVE, the pre-design evaluation, and the POE of the actual design and construction process of the intensive care unit in Seinäjoki Central Hospital. The impact of participation was studied by comparing the results of the pre-design evaluation and POE, comparing the results of the POE against the participation in design in CAVE, and analysing the open-ended comments. The pre-design evaluation and POE were conducted as an online survey. Invitations and reminders to participate were sent by e-mail to the staff. The questionnaire consisted of 116 statements on 13 different topics:

1. yards and entrances,
2. architecture,
3. acoustics,
4. lighting,
5. durability,
6. safety and security,
7. functionality,
8. indoor air,
9. privacy,
10. social interaction,
11. comfort and aesthetics,
12. accessibility, and
13. usability.

After each topic, there was space for open-ended comments. The questionnaire also included questions about the number and quality of statements and the importance of gathering feedback. The same questionnaire was utilized in both evaluations to compare and evaluate the differences in staff satisfaction between the old and new intensive care unit facilities. The response alternatives were “fully agree”, “mostly agree”, “mostly disagree”, “totally disagree”, and “does not concern me”.

The surveys were conducted with the Webropol survey tool. The data were analysed using SPSS 26 Software. The means of the statements for each topic were summarized and the pre-design evaluation and the POE results compared, and the effects of participation in the design were compared in groups, contrasting the results of those who had participated in the pre-design evaluation with those who had not. The independent t-test was conducted to evaluate differences in means. Open-ended comments were grouped under each topic and assembled with similar contents.

# 4 SUMMARY OF THE ARTICLES

The articles were written during the three separate cases using CAVE. The first article was written in 2010 after the HospiTool case where individual participants evaluated the features of the VPs and the use and the experience of CAVE. The second article was written in 2014 after the HospicaseY case where multi-occupational groups evaluated the use of CAVE collaboratively. The remaining articles (3–5) were written in 2019–2022 after the Evicures action research, where the results of the two previous cases gave suggestions for action research in the upcoming healthcare facility design case. These three cases combined the methods and tools to support end-user participation, the actual use of IT methods and tools, and the evaluation of both the use of the methods and tools, and the design process and outcome.

## 4.1 Article 1: CAVE for collaborative patient room design: Analysis with the end-user opinion contrasting method

In this article published in 2010, we studied a case in which individual end-users evaluated four different patient room designs in CAVE, and we collected qualitative end-user opinion data for evaluating the use of CAVE. We examined the features of the CAVE system from the standpoint of the end-user's perception: which features were uncertain, which features were correct or reliable, the experience of using CAVE, and the realism of the presentations of rooms. The method analysed end-user opinions, contrasting real patient rooms with virtual patient rooms.

The case included 22 participants. Eleven of them were patients and eleven nurses. Half of the patients and nurses were interviewed on actual wards and half of them in CAVE. In this case, end-user data were collected in the real hospital environment and later the data were contrasted with the capabilities of CAVE. The case analysed whether the same functions and features could be evaluated in CAVE. It was possible to identify most features, like aesthetics; the correct location of equipment, supplies, and material; distraction by or the good companionship of other patients; window position and size; and living/workspace. There were some uncertainties about sizes and the sufficiency of space. The evaluation of using grab bars or other objects (slippery) was not possible, and evaluation regarding lighting was considered unreliable. For example, temperature, air-conditioning, or noise cannot be evaluated in CAVE. Room size and sufficient space

could be evaluated, but most of the participants were uncertain of the size, even though the rooms were furnished.

The participants were satisfied and able to evaluate features in CAVE, and CAVE assisted in evaluating and determining what the completed room would be like. The participants had a strong illusion of being inside the modelled rooms. The participation in the evaluation was unique for the participants, and CAVE itself was a novelty technology. The participating patients' mean age was 76 years, and they managed to evaluate the rooms and give good observations. They usually sat in a chair or wheelchair. The nurses' mean age was 38 years and their average working experience was 10 years. They evaluated the rooms from the practical side – whether the room was large enough for assisting the patient, whether there was enough space for the needed aids, and whether the doorways were wide enough. As some experienced dizziness during the visits, the navigation speed and motion rate were adjusted to reduce the symptoms. The collaborative design in CAVE continues in the following case to support the design and design process. The use of the VR system might contribute to a transition from the expert-based hospital design process to a more democratic and user-based one.

## 4.2 Article 2: Impact of virtual environment on post-occupancy evaluation results

In this article published in 2014 post-HospicaseY, the impact of using CAVE was studied with a POE questionnaire. HospicaseY utilized multiple tools to encourage and strengthen end-user participation. CAVE was used when evaluating the design of a patient room, a consultation room, and approximately 1000m$^2$ of an emergency centre of a new hospital building under construction. Some 280 participants in 34 multi-occupational groups visited CAVE and 158 of participants filled the questionnaire after visit. The discussions in CAVE were recorded, and in the discussions 14 primary themes and 26 secondary themes were found, with the participants making 4600 observations on the virtual rooms. According to the questionnaire, some 90% of visitors felt (totally agreed and nearly agreed) the visit was useful and evaluation in groups was a good method. The VPs were perceived as real (totally agreed and nearly agreed) by 95% of visitors, and commenting on VPs seemed to be easier than commenting on technical drawings for 90% (totally agreed and nearly agreed) of the participants.

The relevance of participation was studied after one year of the new hospital opening. The POE questionnaire included demographic information and 106 statements on nine different topics (yards and entrances, architecture, indoor conditions, durability, functionality, safety, comfort, accessibility, and usability). Topics were compiled from

studies on CAVE (themes in discussions), EBD literature, and similar POE questionnaires. The link to the POE questionnaire was sent by e-mail to the staff of the new hospital, and 182 staff members (40%) filled it. In this article, the results were evaluated by the difference between two groups – those who participated in design in CAVE and those who did not participate. Some 36 staff members (20%) had visited CAVE, and 146 staff members (80%) had not visited CAVE. The special interest of the study was the difference in satisfaction between these two groups. There were 36 (34%) statements in which the difference between the two groups was greater than 10% in favour of the CAVE visitors. CAVE visitors were more satisfied with the high-quality materials and details, convertible and multipurpose spaces, the spaces for staff, and the safe and accessible bathrooms. There were only two statements – concerning the entrances and number of windows – where the staff members who had not been in CAVE were more satisfied. Many statements were answered with the "does not concern me" option by staff from both groups. These statements concerned the topics of durability, patient privacy, and community. The respondents could comment on the topics, and there were 626 comments on parking, signs, acoustics, furniture, distances, and functionality. The POE survey was regarded by 96% of staff members as important or rather important.

This second case introduced the benefits of POE as systematic tool for all renovation and construction cases and the use of CAVE and collaborative design having some effect to be further investigated on end-user satisfaction.

## 4.3 Article 3: Use of virtual environment and virtual prototypes in co-design: The case of hospital design

This article was the first of the Evicures action research and was published in 2019, post-Evicures. This third article describes an actual hospital design case in which VPs were utilized in the pre-design phase in three iterative cycles. There were altogether 238 participants in 47 groups. The research question was "What kind of VP use supports multi-occupational co-design?" In CAVE, end-users and designers are simultaneously present and work together collaboratively. CAVE provides the utility of full-scale VPs. In this action research, co-design features were used. As end-users were participating in the design of their new working spaces, their opinions and arguments were highly important. Additionally, their interest in participation was stronger, as they could influence their future working conditions.

The results identified three observations. Firstly, 96% of the participants valued the participation as useful (totally and partly agreed) and 95% thought designing in a group was a useful method (totally and partly agreed). Secondly, it was easy for the participants

to improve the VPs and explain their work practices. They could specify why they need space in the patient room and what equipment should be placed in the patient rooms. Thirdly, the participants could identify risks in the transition to single-patient rooms, and solutions to solve these risks were studied. In the case, we found some practical guidelines to organizing CAVE visits that addressed the fidelity of the prototype, the appraisal and change process of prototypes, the optimal number of participants and rounds, the type of navigation, and the length of the CAVE visit.

## 4.4 Article 4: Nurses' participation in the design of an intensive care unit: The use of virtual mock-ups

This fourth article, published in 2021 post-Evicures, studied how nurses' work-related knowledge can be transferred to the design process of spaces in an intensive care unit. In the design, CAVE provided the surroundings for the collaborative design work and face-to-face interaction. Small groups of 4–6 participants saw presentations of the designed VPs. Two intensive care rooms, two intermediate care rooms, private bathrooms, and a nurses' station were modelled in CAVE. The design of these VPs ran in three iterative cycles, and modifications to the VPs were executed in accordance with the feedback from the healthcare professionals. Also, all the participants completed a questionnaire in which they evaluated the rooms and the experience of designing in a multi-occupational group. In this case, nurses were the biggest occupational group, numbering 160 (67%) of the 238 participants.

The results were divided in two parts. First, the comments and requirements for changes were presented and second, the questionnaire was analysed. As the feedback from participants elaborated the design of VPs, the comments were well-founded. The shortcomings of the design were the absence of windows, the placement of the bathroom, visibility, the size and shape of the room, and the lack of equipment. The iteration of VPs solved most of these shortcomings and the VPs in the third cycle were accepted. Only the absence of windows in some patient rooms was an insurmountable issue due to the needed extensions and deep plan. To mitigate the shortage, all patient rooms were provided with dynamic lighting, i.e. the colour of light follows a circadian rhythm. When the acceptable place for the bathroom was agreed upon, the shape of the patient room improved, and it was possible to evaluate the size and necessary space for working and equipment. Visibility was studied from two viewpoints: between two patient rooms and between the patient room and corridor. Visibility was also discussed as a safety issue for assistance and privacy. The third VPs were furnished and equipped so the location and quality of accessories could be evaluated.

Opinions on the use of CAVE were gathered by questionnaire. There were seven statements and an open space for additional comments. The statements were:

1. Participation was useful.
2. The space was real and natural.
3. I felt like I was inside the virtual room.
4. Active participation was easy.
5. Commenting was easy.
6. My opinions were considered in discussions.
7. Designing in a group is a useful method.

Nurses evaluated "Participation was useful" and "Designing in a group is a useful method" affirmatively (totally and partly agreed over 90%). The other statements evaluating active participation, commenting, and dissenting opinions received lower affirmative percentages (totally and partly agreed 80% to 90%), but the percentages rose in the third cycle, as did positive responses to the statements "The space was real and natural" and "I felt like I was inside the virtual room" in the third cycle (totally and partly agreed 96%).

The nurses were satisfied with the process and opportunity to participate in the design in CAVE. Participation was more effortless when there was an opportunity to participate more than once, as this enabled the participants to focus more on evaluating the design features. The nurses felt they got support from other nurses while expressing their opinions. Though the design of these specific rooms was important for the transition to single-patient rooms, the nurses highlighted the need to design larger areas, such as the layout of the whole unit, to comprehend the location of all necessary rooms and their proximities.

## 4.5 Article 5: Staff participation in design with multiple tools: Impact on design and POE results

The fifth article was published in 2022, post-Evicures. Very few studies in healthcare facility design have been conducted in a manner that enables the healthcare staff to participate in several phases. In this case, healthcare professionals took part in the design, pre-design evaluation, and POE of the actual design and construction process of the intensive care unit in Seinäjoki, Finland. The impact was studied by comparing the results of the pre-design evaluation and the POE, comparing the results of the POE against the participation in the pre-design phase, and analysing the open-ended comments. The research question was: "What impact does staff participation in the design of the new intensive care unit have on the results of the POE?"

The new unit has 24 single-patient rooms with private bathrooms. Co-design was used as a method and VPs as a tool in the pre-design phase of the new unit. The staff participated in multi-occupational groups in the design of a single-patient room, a private bathroom, and the nurse charting station in CAVE. Additionally, the staff was represented in the construction project group during the design, construction, and occupation. The new intensive care unit was commissioned in the spring of 2018 and the POE was conducted in the autumn of 2019. The same questionnaire was used in both the pre-design evaluation and the POE. The questionnaire comprised 13 different topics including 116 statements. After each topic there was space for open-ended comments.

Comparing the pre-design evaluation and the POE results, there were improvements in all the topics. There was statistically significant difference in all topics. The biggest improvements in means were in topics of privacy, accessibility, safety and security, and acoustics. There was dissatisfaction due to the lack of windows in some of the patient rooms, difficulties with technical systems, and the size of the new unit.

The results of the POE were compared for two groups: those who participated in the design and those who did not. The assumption was that those who participated in the CAVE sessions would be more satisfied with the new facilities than those who did not. This assumption was found to be incorrect. There were no statistically significant differences in any topics. As a result of the collaborative design phase with VPs, the staff was satisfied with these jointly designed rooms. During the design process, valuable observations and empirical information were collected for the design of the whole intensive care unit, including proximities, necessary spaces, visibility, and access to assistance. The pre-design evaluation and the POE revealed that both topics and statements require clarification and reduction.

The open-ended comments revealed many important issues, such as the need for functional and technical support and checks of the technical solutions' proper function. The open-ended comments were categorized into four classes: space, technology, function, and safety. Many comments were categorized into several classes, like long distances, which affect space, function, and safety issues. The open-ended comments revealed issues to be considered more closely. The biggest concern was the lack of windows in some patient rooms. There were also difficulties in using the automated lighting system due to the settings, presence control, and insufficient knowledge about its use. The air conditioning caused a draft and was noisy at nights. The size of the new unit, corridors, and the layout resulted in long walking distances for staff and family members. There were also comments on the two-floor layout. The new unit's two-floor design was uncomfortable and caused inconvenience for the staff. Although all the spaces needed in patient care were situated on one floor, the siting of the break room, meeting room, and unit leaders' offices on the lower floor was impractical. The two-floor solution was

determined during the architectural design phase. The number of single-patient rooms was deemed non-negotiable, and there were no opportunities to enlarge the floor area, hence the non-patient spaces were relocated downstairs. Furthermore, some spaces were deemed to be too small or too few, such as some patient rooms, which are narrow due to technical issues, and there was a lack of supply rooms or else they were too small.

The respondents considered the feedback collection to be important, and they valued both the pre-design evaluation and the POE. Some 96% of respondents in both surveys thought the gathering of feedback from staff was important. They expected improvements in the exposed shortcomings. In general, the respondents thought that the number of statements was too high, and some statements or topics were difficult to comment on, like yards and entrances and durability. The questionnaire was observed to need updates, but the same questionnaire was preserved during the studies for the comparison of the results. The use of novel design methods and virtual tools needs more case studies and research to maximize all the benefits of the healthcare professionals and the other stakeholders' participation in the design. Additionally, the use of the POE should be made more effortless and the results more easily accessible to promote increased interest and usage.

## 4.6 Findings of the articles

The articles illustrate a continuum of research utilizing collaborative design and VPs in the design of healthcare facilities. The findings of these cases corroborate the utilization of the used methods and tools for more user-friendly approaches in design. Both the individual end-users and multi-occupational groups were satisfied with the participation. With multi-occupational groups, the uncertainties of evaluation diminished as discussion with other participants and testing or simulating functions were possible. Furthermore, the spatial needs of other occupations could be observed. Healthcare professionals could evolve VPs and specify their requirements. Participating more than once in CAVE assists participants in concentrating more on the design. Additionally, the design of the larger layout was expressed, as the location of auxiliary rooms is important, and a functional layout can diminish walking during work shifts. The POE was considered important, and the respondents valued that their opinions were gathered. The POE provided valuable information on the success of the design, the need for technical support for staff, and assurance that the technical solutions are practical and well-functioning. This summary of articles shows how the articles responded to their research questions. The methods and tools for supporting end-user participation in design multiplied as the studies advanced. The findings from the articles are assembled in Table 4.

Table 4. Research questions and articles.

| RQ1. How can a walk-in VE be utilized in the collaborative design of healthcare facilities? | |
|---|---|
| Article 1 | with individual participants<br>participants can be healthcare professionals or patients<br>difficulties when evaluating distances or sizes of rooms<br>all features are not reliably evaluated<br>VE can be used for the comparison of different room models<br>participants had a positive experience<br>nurses considered VE a useful tool for design |
| Article 2 | discussions were more diverse and well-founded in groups<br>design in multi-occupational groups was perceived as useful<br>commenting was easy with a mutual view<br>less uncertainty about sizes and distances<br>VPs appeared to be real |
| Article 3 | useful tool with groups<br>discussions on safety risks and solutions<br>solutions to assist participation (navigation, technical solutions)<br>use of both low- and high-fidelity VPs is needed<br>VPs can be used earlier in the pre-design phase |
| Article 4 | design of larger areas was expressed<br>participants could specify their requirements<br>simultaneous and fast feedback<br>satisfaction with co-design and visualization<br>discussions on visibility, assistance, and audibility in new facilities<br>participation more than once assists commenting and focusing on evaluation |
| RQ2. How can the outcome of collaborative design with a walk-in VE be evaluated? | |
| Article 2 | outcome of design can be evaluated with the POE<br>respondents were satisfied that their opinions were asked<br>open-ended questions produced valuable information |
| Article 5 | using the pre-design evaluation and POE, one can assess the pre- and post-situation in design and find features that need correction<br>setting predetermined quality criteria and assessing their realization<br>when comparing the results of the POE between participants and non-participants, there were no statistical differences between the groups |

# 5 FINDINGS

The objective of this dissertation was to study, develop, and appraise methods and tools to provide equal opportunities for healthcare professionals to participate in the design of healthcare facilities and to evolve design outcomes with their professional competence. The methods and tools included in this dissertation were co-design, and CAVE, where the VPs of designated rooms are presented and evaluated. These methods and tools enable collaborative design, providing the simultaneous presence of multi-occupational groups in CAVE, and designers working together with these groups evaluate and evolve the VPs. Additionally, there were multiple evaluation tools to assess the process and outcome. The use of the methods and tools, and end-user satisfaction were evaluated from three perspectives: participation, methods and tools, and design outcome.

The tools and methods used proved to be profitable. The collaborative design with multi-occupational groups evaluating and evolving VPs simultaneously shows many useful advantages. The healthcare professionals can stay within their field of expertise and justify their needs, explaining their work processes, and, in a group, they can get support from their colleagues. VPs can be used in the earlier phase of the design process, so the participants can take part in the design from the beginning. Low-fidelity VPs resulted in more input into the design, like noticing missing furniture and equipment and proposing the correct location for them. We found general satisfaction with the design when conducting the POEs. When dividing the POE results between participants and non-participants in the collaborative design, there were no statistical differences between the two groups. The findings are presented more thoroughly in the following sections.

## 5.1 CAVE in collaborative design

This section presents two findings when utilizing the collaborative design in CAVE. RQ 1 asked "how can walk-in VE be utilized in the collaborative design of healthcare facilities?" We found CAVE to be useful for collaborative design with multi-occupational groups. Having the participants simultaneously present enables them to contribute to the design with their professional expertise. In addition, the use of VPs permits prototyping spaces earlier in the pre-design stage.

### 5.1.1 Collaborative design with VPs

Finding 1: **Collaborative design with VPs is useful for healthcare professionals.** In the healthcare facility design, the participation of healthcare professionals is important for their expertise in care processes and logistics. The shared visual view assists non-design orientated participants to state and justify their needs within their own expertise. There are many benefits if the participants evaluating the VPs are in the same place at the same time. There are more discussions, opinions, and ideas for design, and the designers get more feedback at one time. Additionally, the learning and understanding of different occupations increase. In CAVE, participants can see their bodies and the same view as the other participants, and they can see each other when discussing and evaluating VPs together. It is easy to show a feature that should be modified or simulate how the work is done, for example, in a patient room. Additionally, in discussions one can see who is speaking and their nonverbal signs.

Through the visual view and chance to show or simulate the work, VPs make it easier for healthcare professionals to comment. They can also give well-argued points for the needed changes, which assists the design and designers. In the case of multi-occupational groups, the needs of different occupations enlarge the knowledge of others' work and assist in discovering spatial similarities and dissimilarities. The features with limitations diminished in the latter studies as the VPs were more technologically advanced, and the participants could compare their estimations with others or simulate the care process to ensure sufficient space.

In all three cases, participants perceived the illusion of being inside the VPs and had a positive stance towards CAVE itself. The nurses considered CAVE a useful tool in the design of hospital environments (Article 1). The usefulness of designing in groups was revealed in the questionnaires used in the second and third cases. Over 90% of the participants agreed with the claims "designing in group is a useful method" and "participation is useful" (totally or partly agreed), (Articles 3 and 4).

The number and quality of comments, features, and changes increased with multi-occupational groups. The participants felt that "commenting is easy" (92%), "active participation is easy" (89%), and "opinions are taken into account" (85%) according to the questionnaire in the third case (Article 3). In the first case, the individual participants evaluated features of four different patient rooms regarding the first impression, space, furniture and equipment, accessories, colours and lighting, functionality, and comfort (Article 1). It was not possible to evaluate all the features that arose in discussions in CAVE, but it shows the potential of collaborative design and virtual tools (Article 2). In the third case, the issues emerging were assistance from other workers, the visibility of patients, and acoustics in the change-over to single-patient rooms (article 4). Not all the

observations the participants made could be evaluated in CAVE, but it reveals that VPs enhance commenting on features that cannot be evaluated in CAVE, but which are important to solve during the design process for workflows or other functionalities (Articles 2 and 4).

To conclude, the collaborative design and use of VPs were perceived as useful and assisted the participants in contributing to the design.

### 5.1.2 Prototyping in the pre-design phase

Finding 2: **VPs enable prototyping in the pre-design phase.** VPs allow the use of prototypes earlier in the pre-design phase than in a traditional design process. VPs can be low-fidelity at first and evolve to a higher fidelity from the feedback of the participants. In the third case of this dissertation, the VPs of single-patient rooms were used in the pre-design phase (Article 3). When using full-scale VPs in the pre-design phase, participants can evolve VPs from the start and comprehensive information for design can be obtained earlier in the design process. In Articles 3 and 4, the development of full-scale VPs is represented in three iteration cycles. We began with low-fidelity VPs to obtain the essential basis for the patient room in terms of size, shape, and number and location of the needed furniture, equipment, and accessories. In addition to the room space, we studied functional features like accessibility and visibility.

As mentioned, the VPs can be low-fidelity at first and evolve to a higher fidelity according to the feedback in the iteration cycles. The fidelity level of VPs affects the users' evaluation. Low-fidelity VPs increased discussion and comments on missing features and their position, whereas high-fidelity VPs were comprehended as ready-made and fewer improvements were suggested (Articles 3 and 4). The features discussed during the design highlighted the need for natural light, the size and the shape of the patient room, and visibility in contrast with privacy (Article 4). The high-fidelity VPs raised fewer comments, and the designs were appraised as complete. High-fidelity VP increased the feeling of real space and immersion (Article 4). At the end of the collaborative design, the jointly designed and accepted rooms were used as architectural plans.

In the second and third cases, the evaluation and evolvement of the VPs was performed with multi-occupational groups. The results of the questionnaires show that the experienced immersiveness was high, as 96% (totally and partly agreed) of participants felt like they were inside the virtual rooms (Article 3). Additionally, when proceeding from low-fidelity VPs to high-fidelity VPs, the experience of being in a "real and natural room" increased from 34% in the first round to 58% (totally agreed) in the third round (Article 4).

## 5.2 General satisfaction with the design outcome

The methods and tools used for evaluation in this dissertation were predetermined quality criteria, pre-design evaluation, and post-occupancy evaluation (POE). RQ 2 asked "how can the outcome of collaborative design with walk-in VE be evaluated?" In these cases, we utilized various methods and tools for evaluating the effects of CAVE, VPs and collaborative design, and the level of end-user satisfaction in relation to the design outcome. Additionally, we studied and compared the outcome of the design in terms of participation or non-participation in the pre-design phase.

Finding 3: **Collaborative design has an impact on general end-user satisfaction**. Collaborative design with full-scale VPs has a positive impact on the advancement of the design process and outcome. Further studies are needed to examine what the impact of the used methods and tools in transferring the expertise and experience of healthcare professionals to the design. In this dissertation, participation in design did not increase satisfaction, however, and there was no statistical difference between the participating and non-participating responders when comparing the results of the POE questionnaire. In the second and third cases, the POE results were divided according to participation and non-participation in the design phase (Articles 2 and 5). The assumption in the third case was that participation in the design phase would enhance satisfaction, but the assumption proved to be incorrect. Although the means in the questionnaires were slightly higher in the second case with participation in the design phase, there were no statistically significant differences (p-value) in any topic between the participant and non-participant respondents. The similarity of the participation and non-participation groups was tested further with Pearson's Chi-squared tests. In the second case, there was a statistically significant difference ($p < 0.001$) between these two groups. The interpretative factors found were workplace and age. When testing the groups in the third case with Pearson's Chi-squared test, there was no statistical difference ($p = 0.539$) between these two groups.

Usually, participation in the design is supposed to increase satisfaction and commitment to the design results (Kujala, 2003). In these case studies, we presumed this would be the case, but thorough statistical calculation showed the premise to be erroneous. The results of the POEs in these cases varied depending on the studied topics. If we consider satisfaction relative to design, it is important that all end-users of a new facility are satisfied with the design outcome, including those not participating in the design. The general satisfaction can be for multiple reasons. One reason could be the experience that the design supports the daily working of different occupations, and the staff succeeded in conveying their professional knowledge and practical needs to the design. The satisfaction with the design of new facilities increased during the design and construction process.

When comparing the results of the POE with the pre-design evaluation results, there were statistically significant differences for all topics (Article 5).

With cases 2 and 3, the staff turnover was high as the design and construction phases took a long time (Articles 2 and 5). As the design and construction phases are usually long, there are challenges in involving healthcare staff, like retirements, leaves of absence, and job changes. The recruitment of new workers explains the low percentages of participants among the design respondents in these two POEs. In the second case, the percentage was 19% (34 respondents of 182), but in the third case, the percentage was higher at 38% (21 respondents of 55). As a result of the collaborative design, it is important that new workers are equally satisfied with the outcome of design.

The POEs of this dissertation revealed that conducting a POE was considered important, and the healthcare professionals valued that their opinions were asked (Articles 2 and 5). In both POEs, 96% of respondents considered the POE important. The healthcare professionals also anticipated improvements to the reported shortcomings (Articles 2 and 5). Including open-ended questions for every topic provides a wide range of observations and comments to broaden the given feedback. Open-ended questions furthermore revealed the importance of continuing functional and technical support for the staff after commissioning and ensuring that the technical solutions are practical and well-functioning. In the feedback meetings, the respondents appreciated that their opinions were considered and there would be improvements to the presented shortcomings.

## 5.3 Summary of scientific findings

The objective of this dissertation was to study, develop, and appraise methods and tools to provide more equal opportunities for healthcare professionals to participate in the design of healthcare facilities and to evolve the design outcome with their professional competence. The methods and tools included in this dissertation are co-design, and CAVE with VPs. The use of the methods and tools and the end-user satisfaction were evaluated from three perspectives: participation, methods and tools, and design outcome. In this summary, the scientific findings are gathered under the research questions and explained with the grounds for each finding.

RQ1 asked "how can walk-in VE be utilized in the collaborative design of healthcare facilities?" The question explores the purpose of use of walk-in VE and collaborative design. Two findings were found. First, collaborative design with VPs is useful for healthcare professionals. The methods and tools assist healthcare professionals to take part in the design, and they can stay within their expertise and justify their spatial and functional needs. They can get support from their colleagues when participating in groups

in CAVE. Discussions and evaluations in groups diminish uncertainty regarding the size of spaces and distances. The advantage for designers is faster and more accurate feedback.

Second, VPs enable prototyping earlier in the pre-design phase. The design of rooms can start with low-fidelity VPs earlier. Low-fidelity VPs enable healthcare professionals to shape rooms optimally and note missing features and identify their placement. Low-fidelity VPs generate more feedback for designers than high-fidelity VPs.

RQ2 asked "how can the outcome of collaborative design with walk-in VE be evaluated?" The evaluation can be conducted from three perspectives: the design process, outcome of design, and end-user satisfaction. First, the design process can be measured with questionnaires evaluating components of design participation, like usefulness, activity, influence, and group work. Second, the outcome of the design can be evaluated by 1) defining predetermined quality criteria before the design and measuring their realization, 2) conducting a pre-design evaluation and a POE, 3) comparing end-user satisfaction levels of the pre-design evaluation and the POE, and 4) comparing the POE results of respondents who participated in the design versus those who did not participate.

Third, collaborative design with walk-in VE has an impact on general end-user satisfaction. There was no statistically significant difference in end-user satisfaction in the POE between participants and non-participants in the design process. This was an unexpected result, as participation usually adds satisfaction. Further research is required to investigate the outcome of the design and the role and significance of collaborative design and visualization in end-user satisfaction.

# 6 DISCUSSION

In this chapter, the scientific findings of the dissertation are assessed together with other studies on collaborative design, VR, EBD, and their findings. The scientific findings comprise the usefulness of collaborative design with VPs, the early utilization of VPs in the pre-design phase, and general satisfaction with the design outcome. The chapter continues with practical recommendations for presenting and evolving VPs. Following this, an assessment of the dissertation's reliability, the validity of the studies, and generalization is presented along with the limitations of the studies. The chapter ends with recommendations for future research.

## 6.1 Scientific implications

As the title of this dissertation "*Exploring Virtual Reality as a Tool for Co-Design in Healthcare Facilities*" states, the cases of this dissertation utilized collaborative methods and VPs and investigated and assessed the findings through end-user satisfaction with the methods and design outcome. The collaborative methods were used in the cases in various levels with individual participants and multi-occupational groups. The collaborative notion used in these studies involved the simultaneous participation of multiple healthcare professionals in CAVE designing together with the architect. The utilization of co-design in the third case with full-scale VPs supported the non-design-orientated healthcare professionals' more equal involvement and brought their expertise and experience to the design.

Visualization adds to the understanding of spaces and aids in commenting on and evaluating the design. As the participants see the same view, it is easier to discuss, point to a feature in question, and suggest changes. When participation occurs in multi-occupational groups, the opinions of different occupations enlarge the understanding of various spatial requirements. One aim of co-design is to add collective understanding to the workplace (Steen, 2011). Moreover, designers get more accurate feedback for the design from a group.

Additionally, it is important to evaluate the level of end-user satisfaction. When comparing the results of the participants and non-participants in the design, we found that there was no statistical difference between these two groups in the POE.

### 6.1.1 Collaborative design with VPs

There are a few similar collaborative studies with walk-in VEs (Fröst and Warren, 2000; Mobach, 2008; Bullinger et al., 2010; Persson et al., 2014), which have similar findings with groups. Fröst and Warren (2000) state that collaborative design including VR provides a method in which the participants can better test their ideas. In his study using participatory design and VR, Mobach (2008) shows that participation brought changes to the design, and additionally staff satisfaction increased, and costs were reduced. Bullinger et al. (2010) combined User Centred Design and PD with VE prototypes in the architectural planning process, and with this method they could make important strategic decisions earlier than in the standard planning process. In their hospital study, Persson et al. (2014) used a digital 3D model, virtual and physical full-scale models, and a mathematical model with participatory design. The virtual full-scale model included the entire area of the proposal unit, and the physical full-scale model a few rooms. Both models were perceived as important, the virtual model for the ability to model larger areas and the physical model for providing tangible properties like rearranging walls and furniture. The study included multi-occupational groups in the VE at the same time (Persson et al., 2014). In the third case, nurses proposed the design of the whole intensive care unit for the better understanding of the location and proximities (Article 4).

Some studies consider physical mock-ups to be important for presence in a space for discussions and simulations (Watkins et al., 2008; Wingler et al., 2019). Joseph et al. (2020) note "The performance of healthcare is essentially a team-based activity that requires multiple people to be in a space and dynamically reacting to the space and each other". The team-based activity and the ability to visualize with VPs, and the observation that CAVEs are more adequate for handling bigger objects (Moehring et al., 2011), show the potential of using walk-in VEs, albeit the trend in use of VR centres on the use of HMDs which is more single-user based (Kim et al., 2013; Kalantari and Neo, 2020; Horvat et al., 2022). Recent studies in healthcare architecture have combined VR with display of Building Information Model for healthcare professionals and patients (Buchanan et al., 2023; Yang et al., 2024). Furthermore, there is a study combining a full-scale physical mock-up with augmented reality to conduct simulation-based design evaluations of trauma rooms (Estejab and Bayramzadeh, 2025). The number of studies shows the need to find suitable virtual solutions for various design cases.

### 6.1.2 VPs enable prototyping earlier

The VPs can be used in an earlier phase of the design than physical prototypes. Usually, prototypes are used in the traditional design process after front-end ideas and concepts (Sanders and Stappers, 2008). New technologies, like VR in this study, enable designing

and evaluating VPs earlier (Sanders and Stappers, 2008), and when choosing the fidelity of the prototype, one can influence the quantity and quality of feedback.

In the third case, the VPs were used in the pre-design phase. In our case, we had only the architect designing prototypes, and the changes did not impact other planners' fields, like electricity or air-conditioning. The fidelity level of VPs affects the users' evaluation. Low-fidelity VPs increased discussion and comments on the size and shape of rooms as well as missing features and their position, whereas high-fidelity VPs are comprehended as ready-made and fewer improvements were suggested in the studies of this dissertation (Articles 3 and 4). In their study, Fröst and Warren (2000) concluded that the simple and low-detail performance of VR models promoted creativity.

When low-fidelity VPs are used, the non-design orientated users have more space to evaluate and develop the presented prototypes (Tiainen et al., 2014). Wingler et al. (2020) proactively studied performance in three different virtual preoperative rooms and compared the results of the given characteristics. Additionally, virtual rooms made it possible to evaluate multiple design options early in the design process to engage end-users and support the EBD decision-making process (Wingler et al., 2020). In other studies, such as that by de Casenave and Lugo (2018), high-fidelity VPs helped professional and even non-professional participants to perform exact design reviews.

### 6.1.3 Impact on general end-user satisfaction

The third finding was that participation in the design process has an impact on end-user satisfaction both in terms of the design process and the design outcome. In the second and the third cases of this dissertation, the POE results were divided according to participation in the design phase and non-participation in the design phase. The assumption in the third case was that participation in the design phase would enhance satisfaction, but this assumption was discovered to be incorrect. The means of the different topics varied in the questionnaires, but there were no statistically significant differences in any topic between the participant and non-participant respondents. The results of the second case were checked statistically with the findings from the third case. Though the results of POE were somewhat higher amongst participants in the design, there were no statistically significant differences between participants and non-participants in design.

In general, it is supposed that participation in design increases end-user satisfaction and commitment (Kujala, 2003). There are some studies that have examined end-user satisfaction with multiple methods. There are in POEs guiding principles and EBD goals (Alzimer et al., 2019) and POEs with different themes and sub-themes to measure end-

user satisfaction (Berry and Parish, 2003; Kotzer, 2011; Ferri et al., 2015). The studies state that participation improves the design and avoids post-occupancy renovations (Reno et al., 2014), participation has increased due to new design methods (Keys et al., 2017), and the number of POE studies with different methods has risen (Göçer et al., 2015; Li et al., 2018; Brambilla and Capolongo, 2019).

The third case of this dissertation was a longitudinal study of the whole chain of the design, construction, commission, occupation, and post-occupancy evaluation of an actual design case in which healthcare professionals participated in all phases, filling the research gap. In most case studies, the healthcare staff participate only in a few stages (see Table 2). The results of the third case provide significant information on a longitudinal case study of all the phases, from design to evaluation. The questionnaire used in the design phase revealed the satisfaction with the methods used in the design. Collaborative design with several participants was found to be useful and resulted in learning and support. The utilization of predetermined quality criteria and their realization, and the pre-design evaluation enhance the evaluation of the success of the design and comparison with the POE. The support for staff after the commission noted in this dissertation to provide functional technological settings has also been noted in other studies (Schreuder et al., 2015; Halpern and Anderson, 2020).

## 6.2 Recommendations for practice

Most of these practical recommendations are familiar to VR researchers and designers and frequent users of different VR platforms, but some ideas from the participants of different occupations might be of interest. The main audiences for the following recommendations of practice are healthcare professionals and designers, but some of the recommendations are useful for other fields where the participation in the design by end-users and professionals of the field is highly recommended. Additionally, some observations are worthy of note when arranging VE visits. When improving quality in design, it is important to get feedback from participants. Below are some recommendations.

Recommendation 1: **Design of larger areas in a walk-in VE.** With a walk-in VE, one can present the design of larger areas than one room to the group. The location of different rooms and the distances between them in the unit are important for healthcare professionals because distances impact the use of time and safety issues during working shifts. Healthcare professionals spend a lot of time walking during their shift (Gurascio-Howard and Malloch, 2007), and the layout of the unit is very important. Usually, the design begins with the individual rooms, like with a physical mock-up or a VP of a room. VR with computer-aided design (CAD) enables the display of the design of spaces from

a larger area in 3D and at full-scale. A walk-in VE enables the display to the group simultaneously. When designing the layout of a whole unit, it helps healthcare professionals to evaluate the locations of the rooms, proximities, routes, visibility, and logistics. In the second case of this dissertation, there was a VP providing nearly 1000m$^2$ of new emergency outpatient facilities to evaluate the entrance, corridors, a waiting hall, and monitoring rooms (Article 2). In the third case designing the intensive care unit, nurses considered the modelling of only the patient rooms, nurse station, and bathrooms as a limitation (Article 4). Issues like the visibility of patients, audibility, and assistance from other nurses in the large unit arose in the discussions (Article 4). In the study by Persson et al. (2014), the virtual full-scale model included the entire area of the proposed unit. The layout of the unit, the location of auxiliary rooms, and proximities are important for daily workflow (Article 4). The larger area included in a VP is an advantage compared with physical mock-ups. CAVEs are more adequate for handling bigger objects (Moehring et al., 2011).

Recommendation 2: **Technical arrangements for display.** Participation in a VR session is still rare for many people, and sessions should be arranged in advance carefully. As most of the participants are using VR for the first time, their task should be explained, and they should be familiarized with the devices they wear and use. They should also be informed of their task. The size of the group depends on the VR platform. In these cases, we used CAVE, and we found that groups of 4–6 participants work well (Articles 3 and 4). There was enough space for all, and everybody had an opportunity to join in the discussions.

The participants who took part more than once considered the participation to be effortless and they could focus more on evaluating the VPs (Article 4). The design was iterative, and the VPs evolved in three rounds. Those who had the opportunity to participate more than once noticed the progress of changes in the design and could assess the improvements.

During these CAVE sessions, there were some signs of simulation sickness, like dizziness and balance disorder. To avoid these symptoms, we fixed the model to the floor level and restricted flying and leaving the bounds of the VP. Despite these actions, there were symptoms when the navigation was automated (e.g. transition from one stop to the next), and when the navigation was too speedy or jerky (Article 3). Additionally, the average visit time (30 minutes) was longer than the present recommendation for HMDs (10 minutes), which might cause some symptoms (Chang et al., 2020).

The navigation should be organized with an experienced navigator to provide a pleasant experience in CAVE, since not all the visitors are familiar with joysticks (Tiainen et al., 2006). Only a few participants wanted to navigate themselves in our cases, and Persson et al. (2014) reported similar experiences in their hospital study.

Recommendation 3: **Set quantitative predetermined criteria for design.** In the third case of this dissertation, there were 11 predetermined quality criteria, and their realization was followed through the case (Article5). When using predetermined quality criteria, the focus should be on concrete targets instead of the experiences and opinions of end-users (Elf et al., 2015). Usually, the success of design and construction is appraised by keeping the construction project on budget and with a low number of post-occupancy renovations (Reno et al., 2014). Increasingly the success of design and construction is measured with energy savings and sustainability (Brambilla and Capolongo, 2019). Surveys to measure end-user satisfaction or setting targets to measure success are not a current practice, though they are increasing (Pati and Pati, 2013; Elf et al., 2015; Schreuder et al., 2015).

In the third case, predetermined quality criteria were set and how they were realized during construction was followed up (Article 5). The predetermined quality criteria, altogether 11 criteria, were compiled from EBD studies and from the recommendations for intensive care unit design (Rashid, 2014; Redden and Evans, 2014; Thompson et al., 2012; Ulrich et al., 2008). All of them influence either patient well-being or staff work performance. For example, the criteria included single-patient rooms, optimal visibility, adequate space round the bed, and the standardization and grouping of patient rooms. Most of the predetermined quality criteria were realized, but the demands for natural light, a view of nature, and windows were realized only partly, as the new facility had a deep plan and new extensions on two sides, and the site was situated in the middle of other surrounding hospital buildings (Article 5).

Recommendation 4: **There are wide benefits of conducting a POE.** In this dissertation, a POE questionnaire was utilized with two different objectives: 1) assessment of the situation before the design and after the design, and 2) assessment of the situation between participation and non-participation in design. POEs have been poorly utilized in the evaluation of healthcare facilities, though there has been research and some studies contributing to the available results, generating new knowledge about the human use of space and providing feedback on key decisions made during the design and construction process (Vischer, 2009).

The benefits concern the design outcome, end-user satisfaction, and learning from design and construction. The POEs in this dissertation revealed that conducting a POE is regarded as important and healthcare professionals valued that their opinions were asked (Articles 2 and 5). In both POEs, 96% of the respondents considered the POE important. Healthcare professionals also anticipated improvements to the reported shortcomings (Articles 2 and 5). They also gave valuable comments on the questionnaire and the number and quality of statements. There were statements in some topics, like on durability and the yards and entrances, that were difficult to comment on. Including open-ended questions for each topic provided a wide range of observations and comments to broaden

the given feedback. Some issues are clearly issues that must be repaired, like technical malfunctions, and some issues can be repaired with extra training, such as the use of new equipment. When having the feedback meetings with staff, they valued that their opinions were considered, and improvements would be made on the presented shortcomings. Usually there is a lack of knowledge of whom to contact after commissioning and whether the shortcomings are remediable.

When using pre-design evaluation, one can explore the environmental and functional features of the current healthcare facility that should be taken account in the design of the new healthcare facility (Article 5). POEs were conducted in the second and third cases (Articles 2 and 5) to measure satisfaction with the design. The results of a POE can be contrasted with the results of pre-design evaluation to compare the before and after situation and the realization of the design. When contrasting the pre-design evaluation and POE results in the third case, there were statistically significant differences for all 13 topics in favour of the POE (Article 5). The highest means were for privacy, accessibility, safety and security, and acoustics.

## 6.3 Reliability, validity, and generalization

In this section, the concepts of reliability, validity, and generalization are discussed in connection to the cases of this dissertation. The two first cases were case studies and the third was an action research. The first case was qualitative and the following two used mixed methods, as the number of participants was bigger due to multi-occupational groups and there were opportunities to make quantitative and statistical comparisons. All these cases were from the actual healthcare facility design and construction projects, and the participants of these cases were predetermined by state of health/willingness (patients) or working shifts/willingness (healthcare professionals).

In the latter two cases, we used mixed methods to ensure reliability and validity. Furthermore, this was necessary because the number of participants increased due to the inclusion of multi-occupational groups. This enabled statistical comparison. The questionnaire used during CAVE visits in the latter two cases was in principle the same, but in the second case the VPs were high-fidelity, and the features and functionalities of rooms were more the focus of the examination. The third case concentrated more on collaborative design from the start of the design with low-fidelity VPs during three iterative cycles.

The first concept to be addressed is reliability – that is, whether it would be possible to achieve the same findings if the study were repeated (Yin, 2018) and whether the research results are reliable. In the first case, the participants evaluated four different patient rooms.

VR technology has developed, and the VPs are better in quality, which assists participants to better evaluate the different features. The arrangements for CAVE visits should be organized to support participation. The second and third case studies had the same questionnaires, and the findings in the questionnaires after the CAVE visits and in the POE were similar. The questionnaires used measured the correct issues, and the change in satisfaction can be seen in the third case. There were open-ended questions to give feedback on the POE, and modifications were made. The result of the POE depends on how end-users experienced their future facilities. The results show in cases two and three that the participants were satisfied with the collaborative design and visualization. There should be more studies to test the methods and tools in different cases to verify reliability.

One issue to be considered is the position of the researcher in the third case. In the third action research, the role of the researcher was different. In action research, the researcher collaborates with participants, is involved in change process, and shares practical and scholarly knowledge. The experience of nursing, the design of healthcare facilities, and evidence-based design facilitated the role of the researcher. The same researcher presented the results of the pre-design evaluation and POE to the unit, and after the pre-design phase participated in the construction, commissioning, and occupation. The researcher worked in the technical department and had no other relationship with the unit. The cooperation between the intensive care unit and researcher lasted almost ten years.

The second concept is validity, which is studied from two different aspects: construct validity and external validity – that is, the multiple sources of evidence and the generalizability of the case study's findings (Yin, 2018). There were multiple sources of evidence (audio recordings transcribed verbatim, questionnaires, field notes). The questionnaires during the pre-design phase in CAVE measured the satisfaction with the methods and tools used and the experience of VR. The questionnaire used in CAVE measured the change in end-user satisfaction during three iteration cycles of the third case. The outcome of utilizing the same methods and tools during the design require study with different stakeholder groups. The design outcome measured with the POE would probably be different, as the design relies on designers, healthcare professionals, and the organization's medical culture and constantly developing technology.

The questionnaire used in the pre-design evaluation and POE was not officially validated, although it has been used in many POEs in Finnish hospitals since 2013 (Petäjä et al., 2025). The POE questionnaire includes relevant topics and statements and provides significant information on the success of the design. The results of the evaluations in this dissertation nevertheless revealed several improvements for the questionnaire, such as a reduction in statements and topics, as some of them were difficult to assess, and there was a positive correlation between some statements, meaning they could be merged. The

same questionnaire was used in both the pre-design evaluation and POE to ensure similarity in the comparison of the results.

The third concept is generalization. The methods and tools used in this dissertation can be utilized in design cases of healthcare facilities and in other public facilities where the occupational and experience-based expertise of workers is significant. The methods and tools are constantly evolving, and the importance of end-user participation in design has been recognized.

## 6.4 Limitations

There are some limitations to the cases of this dissertation. The first was that there was no comparison between physical and virtual spaces. Only in the first case were the features in discussions contrasted as to whether they could be evaluated in CAVE in the same way as in physical rooms. In the latter two cases, only VPs were used. The decision to exclude physical spaces was agreed upon to concentrate on novel methods and tools in the design of healthcare facilities.

The second limitation was that there was only one healthcare organization, but several different units as the object of the studies. In all the cases, there were multiple hospital districts participating and their healthcare professionals were involved in visits to CAVE. In those discussions in CAVE, it appeared that all hospitals are somewhat different in their culture, processes, and facilities. The outcome of the design in other hospital districts would have been very probably different. On the other hand, the methods and tools, and the opportunity to collaborative design with VPs proved to be satisfactory, and this result is probably the same in other organizations.

The third limitation was that a single researcher analysed and wrote up the results of POE in the third case. The data collection was done by gathering the data from questionnaires and the analysis was made with SPSS software. All statistical processing was done separately by independent statisticians. The limitation was addressed by presenting and discussing the results with the technical and intensive care unit staff and analysing the importance of the results and reported shortcomings. After commissioning, it is important to continue functional and technical support for staff.

The fourth limitation is the general applicability of results internationally. The use of similar methods and tools are available, but the results depend on the different designs of healthcare facilities, different workflows, and different healthcare organizations. There are many studies investigating the use of collaborative design and virtual platforms. The participation of stakeholders is considered important internationally. In the same way,

EBD and evaluations have their national and cultural context, though many issues are quite similar.

The fifth limitation is the concentration on healthcare professionals and their opinions and requirements, and the role and experience of architects was not studied in this dissertation. The collaboration between architects and healthcare professionals was comprehensive and unique, as there were over 80 CAVE visits with over 500 participants together in the second and third cases. In general, there was mutual learning by different professions and the professionals gave the reasons for needs and for changes in turns. Participating in these cases aroused the interest of architects to the further utilization of virtual applications in architectural design.

## 6.5 Future research

As the studies in this dissertation indicate, collaborative design and virtual tools assist non-design-orientated participants to evolve the design with their practical expertise and experience, especially when participating in multi-occupational groups. The collaborative design methods and technologies of VEs have diversified. Future studies of VE technologies should review the situation of walk-in VE-type platforms that enable the collaborative design of multiple participants together in the same VE. Of additional interest are new VR technologies to replace walk-in VE platforms, and the organization of simultaneous multi-occupational teamwork in new VR technologies and platforms with augmented, extended or mixed reality.

Additionally, the concept of end-user satisfaction in the design and design outcome requires more research to determine the factors in design and design outcome that enhance end-user satisfaction. The same factors might also affect the end-user satisfaction of those who do not participate in the design.

As mentioned in limitations the role and experience of architects utilizing VR and collaborative design would be an interesting research topic.

The user groups in the design of healthcare facilities have widened and new groups of stakeholders are involved, but their previous experience of VEs might be infrequent. New stakeholder groups comprise different social and healthcare professionals, patients, families, different healthcare associations, decision makers, and companies. As they have different perspectives and needs, it would be interesting to study their satisfaction in participation and their opinion of the opportunity to influence the outcome. There are initiatives to organize educational workshops for user groups and stakeholders (Carthey, 2021) to support participation in healthcare facility design cases and assist participants to

contribute their occupational experience to the design. The progress and results of these educational workshops should be kept in mind and a pilot study should be considered here in Finland.

The utilization of evaluations like pre-design evaluations and POEs to evaluate the success of the design and end-user satisfaction require more studies for usability, availability, and validity. Furthermore, the awareness of evaluations should be increased among decision makers, designers, and healthcare professionals. A common national questionnaire for well-being service counties in Finland would provide feedback and learning on design, usability, sustainability, and end-user satisfaction.

# 7 CONCLUSION

The objective of this dissertation was to study and develop methods and tools for healthcare professionals to provide appropriate techniques to participate in the design of healthcare facilities and to evolve the design outcome. The method used in the design was co-design, and the tools were full-scale VPs presented in CAVE. The research of this dissertation was done within three cases between 2006 and 2019. It has been a privilege to witness enormous technological development of VR. Furthermore, the collaborative design methods have diversified and become more common.

The healthcare professionals were able to participate more equally and bring their occupational and experience-based expertise to the design. Through their feedback, the healthcare professionals were able to evolve the VPs to meet their spatial and functional requirements. Additionally, they considered the co-design with multi-occupational groups to be profitable, and the requirements of various occupations were evaluated in groups. The co-design in groups evolved and accelerated, generating feedback for further design, as the feedback was accurate and well-founded. Healthcare professionals considered the participation to be effortless and useful, and designing in groups was considered a good method. The designing in a group and the shared virtual environment showed a growth in the knowledge and evaluation ability of healthcare professionals in the design process. In co-design, the CAVE settings enable full-scale VPs and allow multiple users to experience the same view, and they can talk, point to features, or simulate their work. Additionally, they can see their own bodies and the other participants and make eye-contact when talking. Work in healthcare settings usually involves multi-occupational teamwork, so when designing spaces for a new healthcare facility, it is also important to have multi-occupational groups participating in the design process. Furthermore, VPs can be used in the early pre-design phase and collaborative design can start earlier. Although the results of the cases were in general satisfactory, the impact of collaboration and visualization did not emerge clearly in the results of the post-occupancy evaluation measuring end-user satisfaction. Participation in the design is supposed to increase end-user satisfaction, but the results show that there was no statistically significant difference between participant and non-participant respondents in the results of the post-occupancy evaluation in two latter cases of this dissertation. This finding requires more research to determine the factors in design and design outcome that enhance end-user satisfaction.

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# ARTICLE 1

**CAVE for collaborative patient room design: analysis with end-user opinion contrasting method**

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ORIGINAL ARTICLE

# CAVE for collaborative patient room design: analysis with end-user opinion contrasting method

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**Abstract** Several studies indicate that virtual reality (VR) systems are useful for end-user participation in an environmental design process. However, these systems can be costly and thus support for the decision whether to invest in a VR of some type is useful. This study presents a novel method for analysing the usefulness of a VR system for the purpose of end-user participation. We collected qualitative end-user opinion data in the real environment and then contrasted this data with the capabilities of a VR system. Additionally, to better understand the capabilities of the VR used, we examined how the end-users perceive the used virtual environment, which in this case was CAVE, an immersive VR system where projectors are directed to the walls of a room-sized cube. In this way, we analysed whether the same functions and elements identified by end-users on the actual wards could also be evaluated in the CAVE. Eleven nurses and 11 patients participated in the study by evaluating a bathroom and/or four patient rooms modelled by the CAVE and the actual hospital wards. The CAVE was convenient for evaluating most issues identified by the study participants in the actual hospital wards, i.e. aesthetics; correct location of equipment, supplies and materials; distraction by or the good companion of other patients as well as window position and size and living/workspace. However, it was not possible to evaluate with full certainty the possibilities for bracing against grab bars or other objects in the VR, and this was found to be relevant to the independent functioning of patients with limited mobility. Also, due to the relatively low luminance levels of projectors, evaluations regarding lighting were considered unreliable. Moreover, end-users were not always certain about the sizes and sufficiency of space in the CAVE. Solutions to overcome these limitations were proposed.

**Keywords** Virtual reality · CAVE · Patient room design · End-user participation · Collaborative design

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## 1 Introduction

Evidence-based design (EBD) is a growing field of science that confirms that some aspects of conventional hospital design contributes negatively to the level of risk and stress. Thus, by improving physical settings hospitals could be more healing, safer and better places to work (Ulrich et al. 2004). Shortfalls in the health care workforce are a global issue that will increase in developed countries due to the ageing of the population (World Health Organization 2006). Hence, it is increasingly important that designs of health care facilities do not cause any additional burden for individuals working in the field. As hospital buildings are likely to remain in place for decades, and as the EBD-literature indicates a relation between physical settings and health, it can be argued that it is useful to invest in building and designing better hospital facilities and so avoid longer-term costs.

Communicating with the end-users group can be crucial in building design. A key issue in this communication is

the way in which the designs are presented to the end-users. Traditional visualisation means are, for example, sketches, scale models and photomontages. In hospital design, full-scale completed mock-ups have also been used to test designs with end-users. However, the use of traditional visualisation tools for user participation can inhibit feedback and cause a loss of information because they lack practicality and easy access to different views (Al-Kodmany 1999), and full-scale mock-ups can be time-consuming and expensive to build. Virtual reality (VR) systems might offer a useful tool for the purpose of conveying ideas to end-users. However, for a hospital design team to decide whether to invest in VR systems, they would have to understand the strengths and limitations of these systems. Further, in order to achieve this understanding, a method that identifies the strengths and limitations of a VR system should be developed.

This paper serves three purposes. First, it presents a case in which end-users evaluate patient room designs with a VR system. Second, and more importantly, it presents a method for evaluating VR systems. The method includes collecting qualitative end-user opinion data in the actual premises that are currently in use and contrasting this data to features of a VR system. With this approach, we examine whether or not the used VR model enables evaluations of all features that are noted to be relevant in the actual environment. The rationale of the method is simple: if some environmental feature is, for example, disturbing in the end-users' perception in the actual environment, the end-users should be able to evaluate this feature also in the VR system. Otherwise, there is a limitation in the used VR system as it does not enable end-users to evaluate the features of the environment that were assessed in the actual environment. The third purpose of this paper converges with the second purpose as it is about examining features of the used VR system in the light of users' perception. More precisely, the paper studies whether the end-users' specifically identify issues about which they are uncertain as to whether the features are correctly or reliably observed in the VR. Also of interest is how the study participants evaluate and experience the VR system itself and whether they consider the presentations in the VR to be realistic.

We have used the CAVE® Automatic Virtual Environment in this research and applied the technology for aiding end-user participation in the patient room design process. CAVE is a VR theatre shaped as a cube with display screens that surround a viewer as presented and defined by Cruiz-Neira et al. (1992, 1993). Participants inside the CAVE can walk around 3D objects and interact with them in real-time. When a user walks around in the CAVE, his movements are being tracked with the electromagnetic sensors as the 3D environment adjusts to the user's perspective.

## 2 Related studies and research aim

Some studies have looked at VR systems in end-user participation in environmental design. Majumdar et al. (2006) investigated the use of VR in a courtroom design. An immersive 3D virtual environment was presented to courtroom judges with a curved front projection screen illuminated by three pairs of projectors. The authors concluded that the design session was shorter with the use of VR than with a completed plywood courtroom mock-up. An important aspect of courtroom design is to achieve appropriate sightlines from the various vantage points of courtroom occupants. VR allowed the occupants to virtually be "seated" in various positions while maintaining the same view for all the participants. This made it easier to focus the shared attention and perspective of the participants on one sightline at a time. Thus, a more rapid consensus building and resolution of issues were enabled.

In Heldal's (2007) study, the use of desktop-based VR was beneficial during a road planning process. According to the results, a majority of the experts involved in the process experienced a more rapid initiation of the dialogue with the public with VR than by using traditional methods. The possibility of rapidly reaching a common understanding in the early stages of the road planning process was found to be beneficial.

Westerdahl et al. (2006) compared end-user experiences in VR to users' experiences in an office building that was completed similarly to the VR model. The VR was introduced with a powerwall movie screen and stereo glasses. According to their results, the VR model made it possible for end-users to foresee what would be the social meeting places, such as places for breaks and coffee drinking, in the soon-to-be completed office building. Furthermore, when questionnaire-based evaluations concerning the VR model and the built building were compared the respondents' views of the office building were in most features similar.

Drettakis et al. (2007) studied the use of a VR environment in domains of architectural design and urban planning. In the study, VR was introduced to the users with a workbench equipped with active stereo glasses and a stereo display. The researchers found that sufficient levels of realism in the VR environment, such as spatialised 3D sound, high-detail vegetation and shadows, as well as the presence of rendered crowds, are significant for the design process and for communicating about designs. They allow a better sense of scale and overall ambience plus a better perception of space and physical objects. Furthermore, the authors reported that respondents found the VR environment to be effective, pleasant and easy to use as a design tool.

Mobach (2008) studied the effects of a VR supported participatory design approach in the construction of two community pharmacies. By studying this, he examined

whether the VR-aided collaborative design process could benefit an organisation in such a way that improves the actual performance of the organisation working in the planned environment. The VR environment was introduced with a cylindrical screen by means of three projectors. Stereo effect was created with shutter glasses. The VR-aided design process resulted in changes in the design, improved staff satisfaction and reduced costs.

Few studies have investigated the use of a CAVE-type VR in a collaborative design process. Fröst and Warren (2000) have presented a study where laboratory layouts were designed collaboratively by using the CAVE. In the study, the end-users made several visits to their future labs in the CAVE. According to the authors, the CAVE helped in the collaborative design process by providing a method with which study participants' ideas could be better formulated, analysed, tested and realised.

Seron et al. (2004) investigated a CAVE-type virtual environment as a tool for a full-size train design. Approximately 600 people visited the CAVE, and according to authors the feedback from them was always positive and enthusiastic. Train companies involved in the project came to the conclusion that CAVE is a better alternative to the physical full-size model of a train. Many changes in the design of the train were made on the basis of the feedback made in the CAVE.

Dunston et al. (2007) described the use of CAVE in producing a virtual hospital patient room. A pilot test, in which nurses were introduced to the CAVE environment, was made. According to the authors, the nurses liked the immersed and interactive sense of the CAVE, which could not be achieved with 3D desktop environment.

In sum, it seems that VR is a useful and effective tool in visualising and communicating ideas to end-users. However, VR systems are quite expensive, especially when considering high-end immersive system such as CAVE, which demands a large infrastructure. It is therefore relevant to critically consider the uses and benefits of such systems. Our approach to this was to study how end-users evaluate non-virtual environments and thus infer what types of evaluations the VR system should facilitate in collaborative design sessions.

Table 1 presents the main research question in a nutshell. Ideally, a VR system should be able to reliably present at least those features that are evaluated by end-users in the actual non-virtual environment.

## 3 CAVE automatic virtual environment

Interviews in the VR environment were performed in the CAVE of the School of Information and Communication Technology at the Seinäjoki University of Applied Sciences (SeAMK). The CAVE in question was based on a cluster of computers. It had five rear-projected walls in a cubic arrangement in a way that it was a full closed cube with the exception of one vertical wall that was absent. Thus, it could cover the user's entire field of view when the user is situated with their back towards the absent wall (see Fig. 1). Digital light processing (DLP) projectors were used to display a stereo image on each wall, giving a three-dimensional view through shutter glasses. The user was tracked by the Flock of Birds magnetic tracking system from Ascension Technology, allowing them to move around in the model (within the physical bounds of the CAVE room). In addition to this, a joystick-like wand could be used for moving longer distances.

The rooms were modelled in 3ds Max from Autodesk, based on CAD models, photographs and floor layouts. Realistic surface materials and lighting were simulated using texture mapping and radiosity methods. The window views were based on actual fish eye photographs. A model for real-time viewing was made by pre-rendering the lighting into texture maps. This model was then viewed and navigated in the CAVE using VR4MAX from Tree C.

### 3.1 Rooms modelled to the CAVE

Four patient rooms and a bathroom were presented in the CAVE environment. All room types and the bathroom concept were represented in one model built around a hospital corridor. Two of the room types, a one-patient room (Fig. 2) (17.0 $m^2$) and a two-patient room (Fig. 3) (25.0 $m^2$), were consistent with Finnish national healthcare guidelines and were to be utilised in a soon-to-be completed hospital building. This new hospital ward is a collaboration project between two Finnish regional health care providers, these being the Central Hospital of South Ostrobothnia and the Health Centre of Seinäjoki. The latter two of the four patient rooms differ significantly from the typical Finnish patient room models, one roughly following the two-bed concept as found in the Swedish Norrtälje Hospital (Fig. 4) while the other was inspired by models used in the USA (Fig. 5). The Swedish design is slightly

**Table 1** Study questions

| Secondary study question: What issues are evaluated by end-users (nurses and patients) in the actual wards? | Main study question:<br>← How does these match →<br>What issues are evaluated in the actual wards but cannot be presented in the CAVE? | Secondary study question: What issues may be presented for end-users reliably in CAVE? |
|---|---|---|

**Fig. 1** The CAVE used in the study

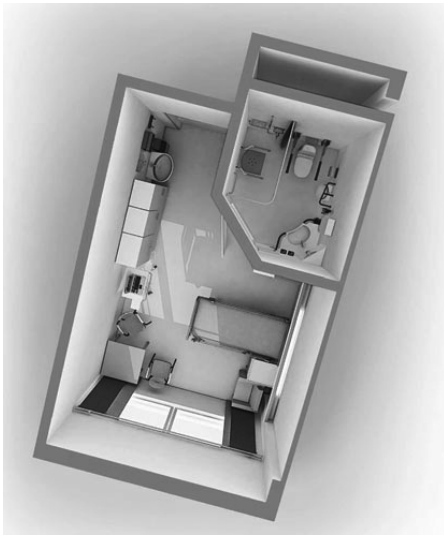

**Fig. 2** Planned one-bed patient room

**Fig. 3** Planned two-bed patient room

larger (29.0 $m^2$) than the planned two-patient room, and beds are located lengthwise opposite to each other and not the usual side by side. One-patient design from the USA introduces a king-size room (29.2 $m^2$), colourful walls and a sofa for visitors and relatives. The bathroom (4.5 $m^2$) incorporated into the model was designed by Väinö Korpinen Ltd with the intention that two caregivers would have enough room to manoeuvre a patient and to create a safe environment for people with limited mobility.

## 4 Methods

The aim was to use a method that allows thoughts and concepts not predetermined by the researchers to emerge during

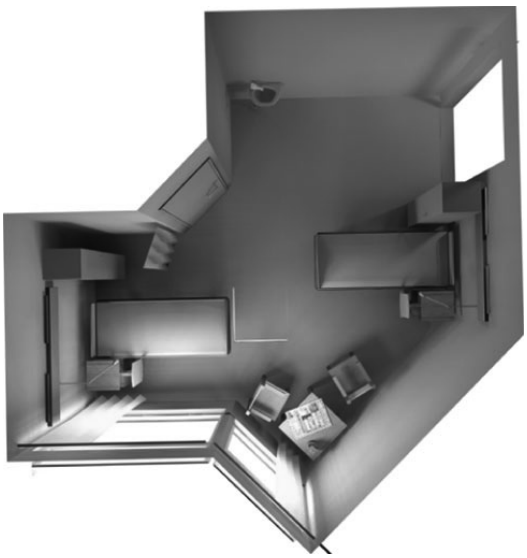

**Fig. 4** Model adopted from Norrtälje Hospital

**Fig. 5** Model inspired by American patient rooms

the study. To achieve this aim, the studies of Douglas and Douglas served as examples, where semi-structured interviews were used to study patients' perceptions regarding hospital environments (Douglas and Douglas 2004) and where respondents were able to photograph hospital environments (Douglas and Douglas 2005). By similar methods, our study explored end-users' views about the environment in the CAVE and in the actual hospital wards.

### 4.1 Study participants

The study participants were nurses and patients from a rehabilitation ward and an acute ward of the Health Centre of Seinäjoki and from a neurological rehabilitation ward of the Seinäjoki Central Hospital. The data collection was made between October 2007 and January 2008.

Six patients were interviewed in the CAVE and six in the hospital wards. One patient was interviewed both in the CAVE and in the actual hospital. The patients interviewed were aged from 43 to 81 years (mean age being 70 years), two of them were males. The patients in the CAVE, of which two were also males, were aged from 56 to 83 years (mean age being 76 years). Nurses in the three hospital wards selected the participants for the study on the basis that participants would have sufficient capabilities to communicate their views and that they would not find the study situation too stressful or physically challenging.

Six nurses, all but one of whom were women, evaluated the environment in the wards. Each of the three wards was evaluated by a pair of nurses. The nurses were aged from 26 to 58 years (mean age being 49 years) and had twenty or more years work experience in nursing, with the exception of one nurse who had less than 2 years work experience. Six nurses were interviewed in the CAVE. These nurses were all women and were aged from 34 to 47 years (mean age being 38 years). They had an average of 10 years work experience (range 3–25 years).

### 4.2 Data collection in the hospital wards

The patients and the nurses evaluated the environment in the wards where they were treated or worked. The patients were interviewed by the researchers. The nurses evaluated their ward in pairs in accordance with instructions given to them. During the interviews, patients' opinions were elicited on the following features: (a) colours, (b) lighting, (c) placement of furniture, (d) surface materials, (e) size of the room, (f) windows, (g) pleasantness, (h) aesthetics and (i) practicality of the room in general. We were inspired to choose these topics because in a comprehensive review of evidence-based design literature, an association has been found between these issues and patient well-being and safety (Ulrich et al. 2004). Opinions regarding these issues were collected first by directly asking whether they, for example, perceived the size of the room to be sufficient. Then, they were asked to explain why they held this opinion. In this manner, the topics listed previously served as starting points, and the discussion that followed was allowed to flow freely.

Patients were also asked whether they would change or add something to the environment, and they were encouraged to express freely whatever came to mind about the environment. In practice, for each room discussed, after other issues had been covered, the participating patient was first asked to tell us what, if anything, they would change in the room and then they were asked to tell anything that

came to their mind that had not yet been discussed regarding the environment. The interviews were recorded, and the features discussed in the environment were photographed.

The interviews were started in the patient's room and then, if the patient was not too fatigued, he/she guided the interviewer and the photographer to other rooms and environments where he/she had spent time during his/her hospitalisation.

The nurses were instructed to evaluate their ward in a certain manner and given a written instruction (see Index 1). They were also given a digital camera to photograph the features they discussed and a digital recorder for recording their discussion. They were instructed to discuss and photograph the rooms and environments, noting which details they found (a) relaxing or stress inducing, (b) aesthetic or non-aesthetic, (c) pleasant or unpleasant, (d) well implemented or impractical for working, (e) well implemented or inconvenient for patient well-being or (f) well or poorly functioning. Furthermore, they were instructed to explain why the environments or features in the environments could be described with some of the previously mentioned adjectives.

### 4.3 Data collection in the CAVE

Before interviews in the CAVE, the study participants were told that if they felt too stressed or if inappropriate feelings occurred during the interview, they could demand a pause or discontinue the interview. Study participants were encouraged to move freely in the CAVE-cube. Longer distances, e.g. from one room to another, were moved by a research assistant with a joystick. The patients were given the opportunity to sit during the interviews. If the patient chose to sit all movement was made with the joystick. The interviews were recorded and videotaped to observe the participants' behaviour (Figs. 6, 7, 8).

The patients' interviews in the CAVE covered the same topics as (colours, lighting, placement of furniture, surface materials, size of the room, window view as well as pleasantness, aesthetics and practicality of the room in general) and were also carried out according to the same principles (an opportunity to speak freely was given and reasons for views were asked) as on the wards.

Furthermore, the patients were asked (a) how they felt about being in the CAVE, (b) if they had any pleasant or unpleasant experiences, (c) did it feel like being inside a real room, (d) how did the experience differ from being inside a real room and (e) could they determine what the room would be like if completed according to the plan presented in the CAVE. It was not certain that the patients would understand the phrase "virtual reality" and thus the phrase "being inside a three dimensional picture" or a similar expression was used in questions regarding the CAVE.

The nurses were interviewed by a researcher with nursing experience and education, but not by the same interviewer who interviewed the patients. The nurses' interviews in the CAVE comprised the following topics: the quality of the room in terms of (a) performing nursing tasks and procedures, (b) the expected influence on patients' self-functioning and (c) the pleasantness of the room. Questions about the CAVE itself were similar to those asked of the patients, with the addition that the nurses were asked whether they found the CAVE a useful tool in the design of hospital environments.

**Fig. 6** Patient interview in the CAVE

**Fig. 7** Patient interview in the CAVE

**Fig. 8** Patient interview in the CAVE

### 4.4 Analysis of the data

Prior to the analysis, all audio recordings were transcribed. The comments made in the actual ward were categorised according to the issues to which they referred. Categorising and annotating the transcript was done with the qualitative data analysis software Atlas.ti.

The first categorisation was made according to the topics presented to the participants by the interviewer. Additional categories were created when a discussed topic did not fit to an existing category. In the second phase, the participants' opinions were examined, and categories were created for different types of explanations.

After categorising the data from the interviews in the actual wards, the interviews performed in the CAVE were also categorised. We examined whether the categories found in the actual ward interviews could also be found in the data collected in the CAVE. Then comments made in the actual hospital wards were categorised according to whether they referred to (1) a feature, which can be evaluated in the CAVE, (2) a feature, which cannot be

evaluated in the CAVE or (3) a feature for which evaluation in the CAVE is not certain.

The interviews in the CAVE were also used to examine instances of respondents reporting some aspects of the environment that could not be observed correctly or reliably in the CAVE or where they were uncertain about their observations. Whether these uncertainties were due to the technical features of the CAVE was also considered. Furthermore, interview data were used to examine respondents' opinions regarding the CAVE itself.

## 5 Results

The following results are presented such that the opinion data collected on the actual wards is contrasted with the discussions in the CAVE and to the technical features of the CAVE. The purpose of our method was to analyse whether or not the used VR model enabled an evaluation of all the features relevant to patient room design. It is inferred that issues and explanations that were brought into the discussion by the end-users in the actual wards indicate what features are relevant for the design process.

We first present the study participants evaluations of the environments in the actual wards. The issues that they commented on are listed. Second, we discuss whether or not these same issues were commented on also by the participants in the CAVE. Possible reasons for differences (or a lack of differences) between these two sessions (actual wards vs. CAVE) are discussed. The third section of the results tells about any uncertainties expressed by the participants in regard to the observations in the CAVE. These uncertainties were taken into consideration when interpreting what can and cannot be evaluated with the CAVE. In the fourth section, we describe whether or not all the issues noted by the respondents on the actual wards (as presented in the first part) could be evaluated with the CAVE, given its technical features. Sections 1–4 of the results are also shown in Table 2. In addition, results are given for how the respondents evaluated and perceived the CAVE itself.

### 5.1 Issues discussed on the wards

The first column of the Table 2 gives categories of subjects that were discussed by nurses in pairs or by an interviewed patient on the wards. Below each category is the labels used in the responses to the discussion on that category. For example, the respondents were asked "What do you like about the colours of this room?" and a typical reply was that the colours did or did not please them. The question was categorised as "colour", while patients' answers were summarised with the labels "pleasant/unpleasant". Categories were also formulated for explanations that referred to some type of behaviour, such as, moving with assistive equipment, helping the patient to move, watching TV or reading or to some type of feature in the environment.

Some categories overlapped with each other. These are indicated where applicable below the subject categories in Table 2. For example, the respondents were asked whether they regarded environments as beautiful or aesthetic, and the answers were explained in terms of colours, forms, sizes and window view, which were also already separate subject categories.

### 5.2 Comparing discussion on the wards to discussion in CAVE

The second column of Table 2 indicates whether the subject or the explanation related to the subject was discussed in the CAVE. Air conditioning, temperature and noises were most likely not discussed in the CAVE because, unlike on the wards, they were stable and relatively pleasant or non-disturbing. Also, on the wards, high door sills inhibited leaving rooms independently with a wheelchair, and one patient reckoned that thicker grab bars would have been better but these issues were not discussed in the CAVE. A lack of discussion regarding the thickness of grab bars or door sills in the CAVE might have been a coincidence or due to the fact that the respondents could not feel the thickness of bars or come in contact with the door sills.

Respondents commented in detail on various features in the CAVE environment, for example, window view; location of equipment, supplies and materials and sufficiency of living and workspace. It is noteworthy that end-users also made evaluations on issues that could not be or were not controlled and modelled with the CAVE. One patient evaluated the CAVE's floor, i.e. the bottom screen, by stating that it was not slippery. Also, even though virtual patients were not modelled in the rooms, the possible distraction or good company of other patients was evaluated on the basis of bed arrangements. In other words, they were able to imagine how a certain bed arrangement enables positive discussions or causes disturbance when residing in a hospital room.

### 5.3 Uncertainties of observations in the CAVE

The third column of Table 2 indicates whether the respondents reported that some issues could not be observed with certainty in the CAVE. In a few situations, patients mentioned that they were not sure about the sizes and distances in the CAVE. One patient explained that the correct height of a toilet seat is relevant for easy use of a

**Table 2** Classifications of subjects discussed and types of explanations given and assessments of whether same topics could be evaluated in the CAVE

| Subject under discussion in the built hospital environment and explanations | Was the topic discussed in the CAVE? | Did some respondents report that they could not evaluate (in full certainty) the topic in the CAVE? | Could the topic be evaluated in the CAVE taking into account the technical features? |
|---|---|---|---|
| *Colours* | *Yes* | | |
| Pleasant/unpleasant | Yes | No | Yes |
| *Temperature* | *No* | | |
| Draft from the windows | No | – | No |
| Pleasant/unpleasant | No | – | No |
| *Air conditioning* | *No* | | |
| Sufficiency of air conditioning | No | – | No |
| *Noise* | *No* | | |
| Slamming of doors | No | – | Not in the used VR model |
| Noisy office environment | No | – | Not in the used VR model |
| Noisy patients | No | – | Not in the used VR model |
| *Windows* | *Yes* | | |
| Pleasant/unpleasant | Yes | No | Yes |
| Sufficiency of window view | Yes | No | Yes |
| *Surface materials* | *Yes* | | |
| Pleasant/unpleasant | Yes | No | Yes[a] |
| Slipperiness | Yes | No | No |
| *Other persons* (also associated to sound/voices: noisy office environment and noisy patients) | *Yes* | | |
| Good company/disturbance | Yes | No | Yes[b] |
| *Placement/size/form of furniture or other items* | *Yes* | | |
| Pleasant/unpleasant | Yes | No | Yes |
| Correct placement of TV | Yes | No | Yes |
| Enables/inhibits helping the patient | Yes | Yes | With limitations |
| Enables/inhibits movement/helps handicapped patients' movement | Yes | Yes | With limitations |
| *Size of the room* | *Yes* | | |
| Pleasant/unpleasant | Yes | No | With limitations |
| Enough room to help | Yes | Yes | With limitations |
| Enough room to move | Yes | Yes | With limitations |
| Enough room for equipment | Yes | No | With limitations |
| *Quality for performing nursing tasks and procedures* (also associated to room size and placement/size/form of furniture and other objects) | *Yes* | | |
| Correctly situated equipment, supplies and materials | Yes | No | Yes |
| *Aesthetics* (also associated to colours, forms, sizes and window view) | *Yes* | | |
| Pleasant/unpleasant | Yes | No | Yes |
| *Lighting* (also associated to window view) | *Yes* | | |
| Pleasant/unpleasant | Yes | No | With limitations |
| Sufficiency for reading | Yes | No | With limitations |
| Sufficiency in general | Yes | No | With limitations |
| Projected from the right direction | Yes | No | With limitations |
| *Moving* (also associated to placement/size/form of furniture or other items, room size and surface materials) | *Yes* | | |
| Door sills as obstacles | No | – | With limitations |
| Grab bars of correct thickness | No | – | With limitations |
| Correct situation of grab bars | Yes | No | With limitations |

[a] Pleasantness of the surface materials based on how they look but not how they feel

[b] Other persons were not modelled in the CAVE. Possible distraction or disturbance by other persons was evaluated on the basis of bed arrangements

toilet and commented that this could not be determined in the CAVE. Another patient said that he could not determine whether from his position the distance to the modelled wall is one metre or two metres. However, he added that he could determine the form of the modelled room.

There were a few situations in which the nurses were not sure if there was enough room for the patient to move or to help the patient. It is hard to determine whether these uncertainties might as well have occurred in a real built environment. To illustrate these cases the comments, translated from Finnish, are presented in the following:

"There is space under the sink and the height is hard to estimate when thinking of a patient with a wheelchair."

"The door of the toilet, I'm not sure if it is wide enough. Perhaps you can go there with a wheelchair, I guess so."

"I do not know how to look at the width of the door, if it is wide enough." [For helping patients.]

All nurses said that it was easy to perceive the size of the modelled room in the CAVE. However, one nurse was not sure whether the USA-type patient room model was bigger than the one-patient room designed for the new ward even though in terms of square meters the American model was clearly bigger (29.2 vs. 17 $m^2$). Another nurse was not sure about the size of room presented in the CAVE when compared to the rooms on the wards. These uncertainties could have been coincidences, due to colours and furniture sizes or due to the technical features of the CAVE.

### 5.4 Contrasting opinion data to CAVE: what can and cannot be evaluated

The fourth column of Table 2 indicates whether a topic discussed in the actual environment could be evaluated with the CAVE, given the technical features of the CAVE. As only a visual presentation was created, no evaluation could be made of temperature, air conditioning and noises.

Issues were identified from the results regarding room size, furniture and moving around in the hospital environment, which could not be perfectly evaluated with the CAVE. On the wards on several occasions study participants based their evaluations on experiences associated with the physical supports and obstacles and their influence on body positions and ability to move one's body. For example, being able to reach and brace oneself against something were important for patients to be able to independently use a toilet, while nurses needed sufficient space to be able to support the patient. In the CAVE, respondents were able to evaluate the modelled bathroom based on visual information but it is questionable whether the visual evaluation is as reliable as actually trying whether there is sufficient space or, for example, sufficient and correctly situated grab bars.

Furthermore, issues relating to room size, furniture and moving might not be evaluated perfectly in the CAVE because respondents did not seem to be able to be sure of all of their observations regarding sizes as noted previously. However, we found no reason why respondents could not evaluate the relative size and location of objects in the modelled room. Therefore, it can be considered that the correct location of equipment, supplies and a TV could be evaluated in the CAVE rather well. This is to say that the end-users could say whether or not objects are roughly in the correct place in the room, though the model used was not ideal for assessing precise fittingness when considering sufficiency of space.

Respondents were able to evaluate the lighting of the modelled room on the basis of window size plus location of lights and overall ambience. However, evaluating absolute light levels is difficult in the CAVE environment. While realistic luminance values can be calculated, they could not be reproduced correctly due to the limited dynamic range and relatively low brightness of the projectors and screens. Thus, it is difficult to evaluate whether the actual absolute light level would be sufficient for performing tasks such as treatment procedures or reading. Also, on the actual hospital wards, one patient complained about a light pointing in the wrong direction thus producing an inconvenient glare that made reading difficult. In the CAVE, however, participants would not experience uncomfortable glare even when staring directly at a modelled bright lamp or the sun.

### 5.5 Experiencing the CAVE

On the basis of respondents' behaviour, it can be estimated that the CAVE produced a strong illusion of being inside a modelled room. One nurse bumped into the wall of the CAVE. After this participants were advised to be cautious of the walls. Also two patients tried to touch objects modelled in the CAVE. Further, two patients that sat in a chair during the interview covered their knees while they were manoeuvred with a joystick through modelled objects such as chairs and beds.

When respondents were asked whether they felt like they were inside a real room, they answered either that it felt like it or that they could imagine being inside a real room. Three reasons were given for how the virtual experience differed from that of a real room. Some respondents noticed the corners and the edges of the physical CAVE-cube, and it was noted that objects in the modelled room could not be touched. Also, as already noted earlier, one patient indicated that he was not sure about the size of the modelled room. All respondents said that they could determine what the completed room would be like if it would be built according to the plan presented in the

CAVE, and all nurses perceived the CAVE as a useful tool for designing hospital environments.

Generally, the respondents had a positive stance towards the CAVE itself. All respondents expressed either that evaluating rooms in the CAVE was a positive experience or that it was not a negative experience. In moving longer distances (e.g. from one room to another) in the CAVE, some of the first respondents interviewed reported a feeling of mild dizziness. When this was noticed, respondents were told that they could shut their eyes or look away from the screens while moving from room to room.

## 6 Discussion

### 6.1 Main findings

The end-users evaluated the modelled rooms of the CAVE in diverse ways and made various detailed remarks. However, the sufficiency of space and room size were not always clear to the respondents. Other relevant issues that were evaluated in the actual hospital wards but which could not be evaluated with complete reliability in the CAVE were lighting, door sills and the usefulness and correct location of grab bars for patients with limited mobility. End-users perceived the modelled rooms as realistic, while the process of evaluating it was seen as a positive experience.

### 6.2 Methodological considerations

In this study, the usefulness of a CAVE-type VR environment was studied by analysing how end-users evaluate actual environments and by interpreting whether these evaluations could be made in the CAVE. Intuitively, it might seem that if the VR environment is not modelled to simulate the intended environment, then the differing designs may lead to different evaluations of the two environments, which may have nothing to do with a biasing effect of the simulation. However, we did not examine whether the end-users would evaluate the two environments—virtual and real—in a similar manner but instead looked at whether the same functions and elements could be evaluated in both environments. This is to say that we were not interested in whether the participants evaluated certain features of the rooms as poor or good or functional or non-functional but rather we were interested in what types of issues they evaluated. It would have been unnecessary to compare whether the rooms in the virtual environment were evaluated, for example, as more functional than rooms in the real environment because this comparison would have told us nothing about difference between VR and real—it might have told us only about differences between the design of rooms in a virtual and a real environment. The principle of identifying what types of issues were discussed but not how they are evaluated was taken into account when categorising participants' comments. For example, when comments like "grab bars *are* correctly situated" and "grab bars *are not* correctly situated", the single category "correct situation of grab bars" was created.

Some of the study participants reported mild dizziness while moving longer distances in the CAVE. It is likely that these feelings were symptoms of virtual environment-induced sickness, i.e. cybersickness or simulator sickness. These symptoms are considered to be caused by a conflict between the vestibular system's sense of movement and the visually perceived movement and/or by display and technology issues of the used VR system (LaViola 2000). For example, dizziness could have been caused by three-dimensional imaging similarly as has been found with users of head-worn displays (Häkkinen et al. 2006). However, it is difficult to estimate with certainty to which extent the used CAVE system caused cybersickness. First, this is because, this issue was not systematically observed in our study. Moreover, it is noteworthy that the end-users were warned beforehand about nausea and were encouraged to request a break or discontinue the study whether inappropriate feelings occurred. This kind of suggestive message may have caused a negative placebo (nocebo) effect among respondents, i.e., expectation of a negative outcome may lead to an unpleasant symptom (Benedetti et al. 2007). In Seron et al.'s study (2004), not one of 600 persons who visited the CAVE felt any motion sickness. Their CAVE was, however, implemented with a different technique to ours.

### 6.3 Strengths of the CAVE

End-users were able to evaluate various environment-related features in the CAVE with detailed comments and they felt they could determine what the completed room would be like. Thus, it clearly seems that the VR system used worked as a tool for end-user participation in the hospital design process. Also noteworthy is the apparent high level of illusion that was perceived by the end-users. On the basis of their behaviour and comments, the study participants seemed to feel as if they were in a real hospital room.

Furthermore, CAVE can be regarded as useful since the overall study process seemed to convince the design team of the soon-to-be completed ward. On the basis of the end-user feedback collected during the study, concrete changes were made to the on-going hospital construction project plans. The one-patient room and the two-patient rooms of the new hospital ward were made bigger, while the couple

of rooms that followed roughly the Norrtälje's model and the American-type patient room were included into the plans for the new building.

The benefits of the CAVE over a physical mock-up have been discussed in previous studies. It has been estimated that the use of CAVE-based virtual modelling is cost-effective when compared to the use of physical full-scale mock-ups. Another benefit of the CAVE is the possibility for interactivity i.e. the modelled room can be adjusted while evaluating the environment (Dunston et al. 2007; Seron et al. 2004). Also, it has been noted that the digital virtual model can be stored more easily than the physical mock-up (Seron et al. 2004). As a result, in our opinion, a benefit of the VR model is that it could be used during to the whole life cycle of the patient room, for re-evaluating and developing the room. This would enable better adaptation to future technological advances and changes in patient profiles that may affect the current criteria for a good quality patient room.

### 6.4 Limitations of and suggested improvements for the CAVE

During this study, some limitations in the used CAVE system were found. Some issues that were evaluated in the actual hospital wards could not be evaluated to the same extent in the CAVE. Key limitations and suggested improvements are presented in brief in Table 3.

It is probably not necessary that the end-users evaluate some of the features that could not be evaluated in the CAVE, such as temperature, air circulation and noise. Patients and nurses are likely to be content if the air conditioning works and if there is a minimal amount of unwanted voices or changes in the temperature. These goals are more likely to be achieved with professional know-how than with end-user participation. However, adding voices to the virtual environment might increase the level of realism and immersion. The infrastructural features of the CAVE enable this. Hospital voices were used in the virtual hospital environment presented by Dunston et al. (2007).

Evaluating lights in the CAVE can be considered problematic as it was not possible to test whether or not the lights would have projected in the right directions so that they would produce sufficient luminance levels without causing unpleasant glare. The planned level of luminescence could be simulated to some extent even with limited brightness levels by adding a glow around an object. The glow would hinder the viewer's ability to see clearly around the bright object, as would be expected in the real world. Simple empirical lens flare models could be sufficient and more sophisticated models, which are based on examinations of physiological causes of glare in human vision, have been developed (Spence et al. 1995). However, it is not clear how well these models would work in the CAVE. Moreover, it is noteworthy that simulated glare would not cause reflections on real-world objects brought to the CAVE. Thus, to test whether the lights would project a distracting glare that would inhibit, say, reading a newspaper, that newspaper would have to be modelled in the VR environment. Further, simulated bright lamps may not induce irritation or energising effects to the same extent as real-world lights. For example, with sophisticated radiosity models, a virtual sunlit room may indeed look correct in CAVE, but ultimately the physiological response is different because the light is not truly as bright as it should be.

Not being able to touch the modelled objects in the CAVE was a limitation since on the actual hospital wards, end-users evaluated environments on the basis of being able to touch or hold features and to brace against things. Touch-based VR systems have been developed (Wall and Brewster 2006); however, it is questionable as to how they would be implemented for this use in the CAVE and

**Table 3** Identified limitations in the VR model used and possible solutions

| Identified limitations in the VR model | Solutions |
|---|---|
| *Perceiving size* | |
| End-users were not always certain about sizes and distances in the modelled rooms. | To ease perception of sizes and distances in the CAVE, distances in figures (Fröst and Warren 2000) as well as virtual avatars of different sizes (children, women and men) and assistive equipments could be added to the model of the hospital rooms. |
| *Lack of touch* | |
| On the actual hospital wards, end-users seemed to evaluate the rooms on the basis of touch. Especially in toilets, being able to brace oneself against correctly situated grab bars was important. | The VR evaluation session could be complemented with an evaluation session in which physical objects are used. |
| *Perception of light* | |
| Due to the limited dynamic range and relatively low brightness of the projectors and screens testing whether or not the lights produce sufficient luminance levels without causing unpleasant glare would be impossible. | To some extent this could be solved by modelling glare into the lights presented in CAVE. |

whether these systems could be developed to hold the weight of the patients.

Not being able to brace oneself against the modelled objects can be considered a major problem especially for evaluating toilets. On the wards, toilets were often evaluated in terms of whether the grab bars were correctly situated. To overcome this problem, physically constructed objects (e.g. a toilet seat and grab bars) should be used in addition to the VR model. Incorporating these into the CAVE room would create additional effort during the evaluation, as moving longer distances in the modelled environment would require the physical objects to be moved in and out of the CAVE scene. Another possibility would be then to recognise the issues for which the touch-based feedback is important and to test these separately from the CAVE sessions.

End-users were sometimes uncertain about the distances and sizes in the modelled rooms. A similar observation was made in a study by Fröst and Warren (2000). In their study, end-users did not always trust the CAVE-based visualisation to present distances and relied sometimes on more conventional tools, drawings and a ruler, for certainty. The authors (Fröst and Warren 2000) proposed that the possibility to have measurements in figures in the CAVE could be one solution to overcome this problem. Additionally, since our study participants were concerned as to whether or not there was sufficient space in the rooms for patients to move, for nurses to work, and for assistive equipment such as wheel chairs, these elements could be added to VR models.

It is possible that end-users were unsure about sizes because actually two size-related cues were present in the CAVE: the modelled visualisation and the physical corners of the CAVE-cube.

As noted earlier, interactivity is one of the advantages of virtual modelling. In a previous study, interactive CAVE-type VR system was used in collaborative hospital environment design (Dunston et al. 2007). However, in our virtual model, this was not done. This was due to time and work-force restrains. Time-consuming programming is a problem that has been discussed by Dunston et al. (2007), who estimate that to make a VR presentation of a room with a completely new computer code can take approximately 6–12 months in an academic research environment utilising student programmers. Healthcare practitioners interviewed for the study reckoned that time-consuming implementation is the prime limiting factor that prevents project teams for new hospitals from investing in VR presentations.

In the project presented here, however, no programming was required because sufficient features were provided by commercial software. The time spent on modelling a room depended on the source material. Equipped with reusable components like hospital beds and other furniture, a room of reasonable quality could be produced in about a week from CAD models and in a couple of weeks from scratch by one person who was familiar with the process.

Modelling hospital rooms with more uncommon and complicated equipment or items, such as operating tables, would have been more time-consuming. Therefore, there is validity in Dunston et al.'s (2007) suggestion that a library of generic objects for VR mock-ups for particular hospital units could be generated to speed up the process. They also propose a central repository where the data can be stored, used and enhanced.

## 7 Conclusion

This paper demonstrates that the CAVE clearly works in harnessing the end-users' perspective and know-how in the collaborative design of patient rooms. Most issues evaluated in the actual wards could also be evaluated in the VR environment, and the overall process had an influence on the design of new wards. Promising results on the use of VR in the design collaboration have also been obtained from previous studies. Thus, it can be argued that VR systems might contribute to a transition from an expert-based hospital design process to a more democratic and user-based one. However, by contrasting end-users opinion data with the used VR model some limitations were noticed and suggestions made. Most importantly, for an even better VR environment, the end-users should be able to summon virtual patients, assistive equipment and nurses into the modelled rooms. These virtual items and figures should be easily manoeuvred to see whether or not there is enough space in different parts of the room.

In addition to evaluating the use of CAVE for collaborative patient room design, our study carries a further insight. What is needed from a VR system can be determined by studying how end-users evaluate actual environments. This can be done qualitatively, so that end-users may freely express themselves, that is, not with scales and numerical measures that may restrict end-users to the categories and dichotomies presented by the researchers. We label this method as *the end-user opinion contrasting method for virtual environments*. We offer it as a practical means for industry when considering the purchase of a VR system for end-user assisted design projects. By first studying how end-users evaluate real environments, it becomes clearer what kind of VR model is needed to enable evaluations of relevant issues. For example, if tangibility and touch are important in the overall collaborative design process, some type of augmented virtuality, in which real-world objects are merged into the virtual theatre, or a physical mock-up instead of virtual one could be considered.

Positive feedback from our partners is leading towards a continuation project. The hospital extension project in Seinäjoki, Finland, from which part of the patient room designs originated, is interested in further developing the collaborative hospital design process. The plan is to extend the use of CAVE from patient room design to the collaborative design of other hospital premises, such as emergency rooms.

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## Index 1

Research guide for nurses [Translated from Finnish]

To develop the designs of hospital facilities, we wish that you photograph rooms, spaces and details of spaces in your hospital ward that are according to one or both of you

| | |
|---|---|
| –Relaxing | –Stress inducing |
| –Aesthetic | –Anaesthetic |
| –Pleasant | –Unpleasant |
| –Well implemented for working | –Unpractical for working |
| –Well implemented for patient well-being | –Inconvenient for patient well-being |
| –Well functioning or | –Poorly functioning |

We would also like you to report what features of the photographed objects are relaxing or stress inducing, aesthetic or anaesthetic, pleasant or unpleasant, well implemented or unpractical for working, well implemented or inconvenient for patient well-being or well or poorly functioning. Further, please explain why you have this opinion. You can tell freely from different thoughts and experiences. Also, report to the recorder when you leave or enter a room. When you enter a room please mention the room number and tell what type of room it is.

You can move on the ward freely and choose the rooms as you wish. However, to obtain your opinions comprehensively, we wish that you visit at least one of each of the rooms listed below:

____one-patient room
____two-patient room
____three- or four-patient room
____patient room bathroom
____public toilet
____office
____lounge
____coffee room
____storeroom
____pharmacy
____utility room
____showers

You can mark the rooms that you have visited. Furthermore, you can also observe the passageways and window views. Do not take identifiable pictures from the patients.

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# ARTICLE 2

**Impact of Virtual Environment Utilization in Post Occupancy Evaluation**

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# IMPACT OF VIRTUAL ENVIRONMENT UTILIZATION IN POST OCCUPANCY EVALUATION RESULTS

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## ABSTRACT

This paper introduces results of post occupancy evaluation conducted after one year function of new hospital facilities. Questionnaires were completed by 182 members of staff and 227 patients. The form consisted of demographic information and 106 statements on nine different topics, which included yards and entrances, architecture, indoor conditions (lighting, acoustics and atmosphere), durability, functionality, safety, comfort (privacy, community and aesthetics), accessibility and usability. Topics were compiled from observation and studies in virtual environment, literature and similar studies. Studies of evidence based design assist to focus on relevant topics. The special interest of study was to compare the difference between the evaluations of the end-users/staff members who had visited the virtual environment (CAVE) during the design phase and the evaluations of those who did not participate in this design process.

HospiCaseY project (2009-2011) investigated end-user participation in the design and evaluation of healthcare facilities. The project was part of the Spaces and Places 2008-2012 program by the Finnish Funding Agency for Technology and Innovation (TEKES). One patient room, one consulting room and almost 1000 square meters of emergency outpatient facilities were modeled in the virtual environment (CAVE). The total number of visitors during years 2009-2010 in CAVE was just over 280. The actual hospital was opened in September 2012 with the post-occupancy evaluation being undertaken in October 2013.

The evaluation of the success of the design, construction and operational processes is poorly undertaken in the Finnish healthcare system. The use of the systematic evaluation process has not been introduced in any hospital district in Finland. The design process could assist the advancements of other construction projects with the use of systematic evaluation.

In comparison of questionnaire statements the defined criteria between CAVE-visitors and other staff members was over 10 % difference. The number of those statements was 36 (34 %) in total. The CAVE-visitors were more satisfied with the design outcomes than other staff. The statements covered topics which included architecture, acoustics, functionality, comfort, accessibility and usability. There were seven statements achieving a difference of more than 20%. Only in two statements other staff was more satisfied and this related to entrances and number of windows.

### Keywords

Virtual environment, post occupancy evaluation, evidence based design, end-user participation

# 1 INTRODUCTION

HospiCaseY project (2009-2011) investigated end-user participation in the design and evaluation of healthcare facilities (Yli-Karhu et al., 2011). The project was part of the Spaces and Places 2008-2012 program by the Finnish Funding Agency for Technology and Innovation (TEKES). One patient room, one consulting room and almost 1000 square meters of emergency outpatient facilities were modeled in the virtual environment (CAVE). The total number of visitors in CAVE was just over 280. There were 34 multi-professional groups, and all the visits were recorded and videotaped. The actual hospital was opened in September 2012.

The HospiCaseY project supported the design process of the real hospital facilities of the Hospital District of South Ostrobothnia. The "Y-talo" hospital building was a 58 million Euros extension project and was one of the biggest hospital projects in Finland at that time, resulting in increasing the capacity of the whole hospital by nearly a third, 33870 square meters in total. This extension has been in the strategic plan since 2003 and was completed in 2012. It involves almost the building of 1400 rooms, 134 beds and facilities for 20 different units. The new building employs approximately 450 people. Part of the new facilities is occupied by the primary healthcare services of the City of Seinäjoki.

The computer-assisted virtual environment (CAVE) used in the project is a room comprising of three walls, a ceiling, and a floor. The fourth wall is open allowing entrance into the CAVE. Images generated using computer graphic cards are projected onto these surfaces, which, when viewed through stereoscopic glasses, are transformed into a three-dimensional full-scale environment. Surrounding the CAVE there is a larger, darkened room where the projectors are placed. The CAVE solution used in the project comprised five surfaces onto which images were projected. The size of walls is measured 3.0 x 2.5 metres. Modelling was based on Autodesk 3DS Max software. The virtual environment (CAVE) is situated in Seinäjoki University of Applied Science.

One important property of a CAVE-type virtual environment is its scale, i.e. the ability of visitors to perceive the environment as almost real. Visitors are able to move to some extent within the space itself and to travel longer distances with the help of a 3D mouse. Another important characteristic is the quality of the virtual environment; in this case, the environment also featured realistic lighting and shadows, surface structures, colours, views out of windows, and the furniture/accessories situated in within the room.

The project included models for three different environments: 1) a patient room, 2) a consulting room and 3) an emergency centre. These environments were selected because hospitals regularly have multiple identical consulting rooms and patient rooms. The emergency centre is a new kind of unit, and its design involved several new functionalities.

The end-users visited the virtual environment in multi-professional groups of 6–10 visitors on average. Each visit lasted for an hour. All conversations that took place in the virtual environment were recorded and video-taped. After the visit, each visitor was asked to

complete a questionnaire in which they could analyse the properties of the projected spaces more systematically. The objective behind using several simultaneous evaluation methods was to ensure the scientific scope of the analyses. The visitors were also asked to give feedback on the usefulness of the virtual environment.

The HospiCaseY project included another design tool to promote end-users´ participation. A systematic user-orientated feedback system, a web-based post occupancy evaluation (POE) was developed for renovation and construction projects of healthcare facilities in order to assess the success of design, construction and operational processes. A package of statements was compiled from the literature, other similar POE questionnaires and through experiences and studies in CAVE during the project. The feedback system enabled to support the end-user participation, to learn from each project in order to design better healthcare facilities. The feedback system will also strengthen qualitative knowledge and other attributes which are difficult to measure. For this purpose, the feedback system includes statements on topics on evidence based design studies.

Post occupancy evaluation was conducted one year after the opening of the new hospital facilities. Questionnaires were completed by 182 staff members and 227 patients. The form consisted of demographic information and 106 statements on nine different topics: yards and entrances, architecture, indoor conditions (lighting, acoustics and atmosphere), durability, functionality, safety, comfort (privacy, community and aesthetics), accessibility and usability. From all the staff members 36 had visited the CAVE and had participated in the design process during HospiCaseY project in 2009-2010.

This paper introduces results of post occupancy evaluation conducted in October 2013 after one year function of hospital facilities. **The special interest of study outcome is the difference between the evaluations of those end-users who had visited virtual environment (CAVE-visitors) and the evaluations of those (other staff members) who did not participate this design process.**

This paper is structured as follows. First the previous studies of virtual environment, evidence based design and post occupancy evaluation are described. Secondly the studies and the research processes are outlined. Third the study results are presented. The paper concludes with discussion of implications and limitations.

## 2 STATE OF THE ART

The evaluation of the success of a design, construction and operational processes seems to be poorly reported in the Finnish healthcare system. Some independent evaluation has been undertaken, but the use of a systematic evaluation process has not been introduced in any hospital district in Finland. The use of evaluation in the design process would be advantageous for the future projects. The lack of evaluation is puzzling, since there is ongoing period of intense construction of Finnish hospital facilities for the future (Punnonen, 2013).

Evaluation is extensively utilized for decades internationally (Preiser, 1995). Evaluation was launched to identify problem areas in existing building, to test new prototypes of buildings and to develop design guidance and criteria for future facilities (Preiser, 1995). With the use of evaluations and studies a lot of valuable information of usability and the relevance of facilities to patients and staff members' well-being have been gained (Apple, 2012, Kotzer et al., 2011). Evidence based design has contributed for decades requirements of patient recovery and well-being and staff´s job satisfaction (Ulrich et al., 2008). Furthermore there should be more consideration about the impact of healthcare facilities on economical and functional outcomes (Carthey, 2006, Friesen et al., 2008). Other important outcomes are staff productivity, work process efficiency and sustainability from the organizational point of view (Steinke et al., 2010).

Evidence based design is a process for the use of current best evidence from research and practice in the making of decisions about the design of the project together with an informed client (Hamilton and Watkins, 2009). The studies have revealed a great quantity of environmental issues to support patient and staff outcomes (Ulrich et al., 2008). Besides positive distractions, like art, nature, high-quality material and furnishing there are multilateral economical impacts to patients, staff and healthcare in its entirety (Ulrich et al., 2008). The means to decrease infections, falls, medical errors or stress and shorten the time spend in hospitals (Ulrich et al., 2008).

The outcomes of evidence based studies are exploited in the design of new healthcare facilities as well as in contemplating questionnaires for pre- and post occupancy surveys (Kotzer et al., 2011). The outcomes from surveys return new evidence. Carthey (2006) defines POE as "the systematic evaluation of health service buildings or facilities" assumed to occur sometime after their occupation and usually after a defined period of use such as 12 months to 2 years. The systematic use of POE encounters number of obstacles such as not being part of standard design services or adequately funded (Carthey, 2006). POEs are produced as case studies and not utilized continuously in organizations. In many countries orientation is to establish and adopt the methodology as a standard for use on all its projects (Carthey, 2006; Learning from our buildings, 2002).

It is crucial that end-users participate in the design process and provide their expertise for future developments with the design process. The design process requires seamless cooperation and new tools to enhance end-user participation. New tools to facilitate communication between designers and end-users are continually studied, but the systematic use of these tools appears to be rare but growing in number (Haapalainen, 2007, Tiainen et al., 2013).

The use of 3D modeling, BIM (Building Information Modeling) and virtual environment facilitates end-users to specify their requirements and review the design solutions (Dunston et al., 2007, Shen et al., 2012; Yli-Karhu et al., 2011). The use of virtual environment enables to model larger areas than physical mock-up rooms. In HospiCaseY project area for the emergency center was modeled on 1000 square meters (Yli-Karhu et al., 2011). Virtual environment can be utilized with professionals to test prototypes and observe working routines (Tiainen et al., 2013) as well as be to study user experience and perceptions in the design process (Kaapu

& Tiainen, 2010). CAVE can be utilized with single end-user (Wahlström et al., 2007; Yli-Karhu, 2008) or with multi-professional groups (Yli-Karhu et al., 2011).

The use of technological applications without common language for communication and understanding is challenging. The end-users are not usually familiar with the design and construction process, but experts in their own field and need to be considered as equal partners. Absence of common language and suitable methods create a gap between designers and end-users (Shen et al., 2012). Methods to simulate daily activities, working routines and work flows are crucial for designers (Shen et al., 2012, Davies, 2004). Such methods studied to facilitate end-user participation are pre-occupancy evaluation, user pre-occupancy evaluation (Kotzer et al., 2011, Shen et al., 2012), and participatory design (Davies, 2004). Participation in the design process contributes learning and is essential to stipulate common objectives (vision) and methods of planning (Haapalainen, 2007). Participation in the design process appears to be a critical psychological and social occasion (Davies 2004, Wahlström et al., 2010). The design process involves that end-users' feel to be included and their needs to be considered (Davies 2004). In the design process of healthcare buildings not only the impact of staff members is enough. Though nursing is increasingly turning to patient- and family- centered, should even more attention to be paid on collaborative design of physical environment supporting patients and families (Kotzer et al. 2011).

# 3 APPROACH

HospiCaseY project developed and explored tools to encourage and strengthen end-user participation in the design process of a new hospital building. The project was linked to the Y-talo design and construction project, which was supported by this project. End-users (doctors, nurses, staff from administration and maintenance) visited the premises of the virtual hospital and were able to influence to some extent the design process of the new hospital premises. For example changes included the positioning of furniture, windows between observation beds and location and type of accessories. Approximately 20 changes were made in virtualized spaces, which in real terms multiply up to 100 consultation and patient rooms and bathrooms. Also valuable comments were received on colours, furniture, number of accessories and future functionality. According to the questionnaires over 90 % of visitors "strongly agreed" or "nearly agreed" the usefulness of the design in the virtual environment and in groups. The spaces in virtual environment appeared to be "real" for 65 % of visitors and "nearly real" for 30 % of visitors, where 90 % of the visitors stated that making comments in virtual environment was considered "easy" or "relatively easy".

A total of 34 recordings were made of group interviews. Ten of the recordings dealt with the patient room and the adjoining bathroom, thirteen recordings discussed the examination room, and seventeen recordings related to the emergency centre. Some of the visitor groups tested all three virtual environments.

The content analysis of recordings revealed a total of 14 primary themes. After a further analysis of comments, a total of 26 additional secondary themes were identified. The primary themes and secondary themes are listed in Table 1 below. The visitors made a total of almost 4600 observations.

Table 1 Primary and secondary themes of the analysis

| Primary themes | Secondary themes | |
|---|---|---|
| Layout | Accessibility | Safety |
| Accessibility | Ergonomics | Type |
| Furniture | Aesthetics (art) | Accessories |
| Accessories | Hygiene | Lighting, daylight |
| Materials | Practicality | Blinds/curtains |
| Durability | Openability of windows | Attractiveness |
| Ergonomics | Furniture | Colours |
| Hygiene | Touchability | Privacy |
| Safety | Positioning | Acoustics |
| Lighting | Need | View |
| Colours | Dimensions | Durability, ease of maintenance |
| Blinds/curtains | Layout | Materials |
| Aesthetics | Functionality | Appeal |
| Virtual environment | | |

A systematic user-orientated feedback system using a web-based post occupancy evaluation (POE) questionnaire was developed to obtain views from the end-user on the renovation and construction projects of the new healthcare facilities and the success of the design. A package of statements was compiled from the literature, other similar POE questionnaires and through experiences and studies in CAVE, during the project. The feedback system enabled to support end-user participation, learn from each project and design better healthcare facilities. The feedback system will also strengthen knowledge of qualitative or other attributes difficult to measure. For this purpose, the feedback system includes statements on topics, which are objects in evidence based design studies.

The experiences and studies in CAVE generate in content analysis 14 primary themes and 26 secondary themes of discussions in CAVE. The visitors made almost 4600 observations in CAVE. These themes prove to be similar as the topics in other international questionnaires concerning POE (Friesen, S et al., 2008, Learning from our Buildings, 2002, ASPECT and AEDET, 2007[1])

The POE questionnaires were tested during the HospiCaseY project in four minor areas in order to check, if the statements were easy to comprehend, answer and to understand the length of time it took to complete the questionnaire. A few modifications were made to the questionnaires following this process.

1 R&D Project B(04)03 – Disseminating good practice (GDP): developing an exemplar layer for AEDET Evolution and ASPECT. available at www.wales.nhs.uk (accessed 18 May 2011).

The form consisted of demographic information and 106 statements of nine different topics: yards and entrances, architecture, indoor conditions (lighting, acoustics and atmosphere), durability, functionality, safety, comfort (privacy, community and aesthetics), accessibility and usability. Architecture topic includes questions of scale, scheme, value, materials and way finding. In addition all the topics had a free space at the end of topic for comments. The questionnaire for patients and visitors had the same statements but excluded the topics of functionality, durability, safety (partially) and statements of staff comfort.

The Web based survey for staff members of the new hospital facilities was executed by Webropol, online survey and analysis software. The timing for the survey was agreed to be after one year's since the opening of the new facilities in order to ensure that there had been sufficient usage of the new facilities. Permission to conduct the survey was applied from both hospital organizations, whose staff members work in the new facilities.

Information about conducting a survey was sent by email to managers and by email to members of the common information group of workers in the new building. Information was also available on hospitals intranet news. A reminder was sent a week before the survey was to end. At the same time, the patients and their relatives received paper questionnaires at the time of their registration. A 1000 paper questionnaires were distributed to all the units according to the daily patient flow or the number of inpatients. Participation to the survey was voluntary both to the staff members and patients.

## 4 RESULTS

This study compared the differences between the evaluations of those end-users, who visited CAVE (CAVE-visitors) during HospiCaseY project and the evaluations of those staff members (other staff members), who did not participate in the design process. There were altogether 182 staff members who completed the questionnaire. The response rate of staff members was 40 %. 36 staff members (20% in total) had visited CAVE and 146 staff members (80%) did not participate in the design process. The table 2 below shows the demographics of the staff groups.

106 statements were in the questionnaire. The choice of the responses was "strongly agreed", "nearly agreed", "nearly disagreed", and "strongly disagreed". Response "not concerns me" was also possible to choose as an answer. The choices provided were set so, that participants should decide on either agreed or disagreed responses.

The defined criteria to claim that the statement was "good", the number of responses "strongly agreed" or "nearly agreed" had to be over 50 %. The quantity of such statements was 86 (81 %).

The number of statements where the percentile stayed under 50 % in both groups was 20 (19%) and this related to statements were concerning parking, acoustics of reception desks and open offices, patients and staff access outdoors, room temperature and ventilation. There were a big group of statements where staff answered "not concerns me". These statements related to topics such as durability, patients' privacy and community.

Table 2 Demographics of the staff groups

| Demographics | | CAVE-visitors | Other staff |
|---|---|---|---|
| **Sex** | Male | 19 % | 12 % |
| | Female | 81 % | 88 % |
| **Age** | Less than 30 years | 3 % | 19 % |
| | 30 - 34 years | 6 % | 16 % |
| | 35 - 39 years | 8 % | 9 % |
| | 40 - 44 years | 11 % | 19 % |
| | 45 - 49 years | 19 % | 10 % |
| | 50 - 54 years | 17 % | 10 % |
| | 55 - 60 years | 25 % | 13 % |
| | Over 60 years | 11 % | 4 % |
| **Profession** | Medical doctors | 11 % | 6 % |
| | Academic researchers | 6 % | 6 % |
| | Assistant medical doctors | 0 % | 2 % |
| | Auxiliary staff | 0 % | 7 % |
| | Nurses | 56 % | 46 % |
| | Maintenance staff | 3 % | 6 % |
| | Auxiliary nurses | 12 % | 24 % |
| | Administration staff | 23 % | 3 % |
| **Working experience** | Under 1 year | 0 % | 8 % |
| | 1-5 years | 3 % | 21 % |
| | 6-10 years | 19 % | 23 % |
| | 11-20 years | 19 % | 17 % |
| | Over 20 years | 59 % | 31 % |

To compare differences between CAVE-visitors and other staff members, the criteria was defined to be over 10 percent. The number of those statements was 36 (34 %). The CAVE-visitors were more satisfied with the design outcomes than other staff. These statements related to topics e.g. architecture, acoustics, functionality, comfort, accessibility and usability. There were seven statements achieving a difference of more than 20 percent as shown in table 3. Only in two statements the other staff was more satisfied and this related to entrances and number of windows.

Table 3 Statements with over 20 percent difference

| Statements | CAVE-visitors | Other staff |
|---|---|---|
| Materials and details are of high quality | 91 % | 68 % |
| All applicable spaces are convertible and multipurpose | 69 % | 43 % |
| Patients have an opportunity to pray alone or with loved ones | 62 % | 41 % |
| View outside is interesting or of a comforting nature | 58 % | 32 % |
| Staff have good facilities to change their clothes and keep their belongings | 94 % | 73 % |
| All the washrooms and toilets are accessible and safe | 94 % | 74 % |
| All the important objects have a reserve power system | 94 % | 71 % |

The best assessments (the quantity of responses "strongly" or "nearly agreed" were over 80 %) gained by 49 (46%) statements. The end users from both groups were satisfied to issues concerning architecture, lighting, cooling, quality of air, safety, possibilities to wash hands and the quality of maintenance. In some statements concerning on lighting and cooling, there was discontentment with the absence of controls to adjust lighting and ventilation. Some responses stated that there was a draught from the ventilation and that it was set on too low a temperature. Table 4 presents the best and the lowest valued statements of each topic.

After every topic there was space left for comments. Altogether 626 comments were given. CAVE-visitors made 159 comments and other staff 467 comments. The issues which generated most comments were parking, signs, acoustics, indoor conditions, furniture, distances and functionality.

Here are some selected comments on questionnaires:

Parking:

*"The car park is too small as currently in this periphery province, where there is no public transportation as in big cities. This is not fully reckoned with design."*

*"The car park for staff is too small and other car parks are far away."*

Signs:

*"My opinion is that the signs outside are easy to understand, but we still have patients every week who have used the wrong entrance."*

*"Texts on doors are sometimes illogical; some sort of color contrast should be used in the signs along with bigger letters.*

Table 4 The best and the lowest valued statements on each topic

| Topic | Best valued statement | Lowest valued statement | Notes |
|---|---|---|---|
| **Yards and entrances** | Yards, footpaths and stairs have appropriate lighting and are well-maintained | There is sufficient car parking for patients, disabled, visitors and staff | Carparking under 50% |
| **Architecture** | Architecture of building match with the shape, materials and colours to surroundings | Parts of the building have their own appearance to help people to find their way | All statements over 50% |
| **Indoor conditions** | Automatic control of lighting is a practical solution in toilets and bathrooms | Acoustics of reception desks and open offices is sufficient | Acoustics of reception desks … under 50 % |
| **Durability** | Materials of fixtures are durable and easy to clean | Indoor ceilings are durable and easy to clean | High number of "not concerns me" responses |
| **Functionality** | Functional objectives achieved in the new facilities | Way of working and spatial design save steps | CAVE visitors all statements over 50 %, other staff 3 under 50% |
| **Safety** | Emergency exits, fire alarms, fire extinguishers are easy to find | Announcements can be heard in all necessary places | All statements over 50 % |
| **Comfort** | Spaces are clean and well-maintained | Patients can make drinks and snacks in wards | High number of "not concerns me" responses concerning patients sociality |
| **Accessibility** | All the footpaths and corridors are accessible | Acoustics are suitable for the hearing impaired persons | All statements over 50 % |
| **Usability** | Available space for units is sufficient | All controls for adjusting lighting and ventilation are easy to use | All controls for adjusting … under 50 % |

Acoustics:

*"The ventilation makes a loud noise, especially at nights."*

*"The legs of the chairs in the canteen make a nasty noise because of the type of the floor covering used when the chair is scrapped across the floor. It is very unpleasant to hear."*

*"There is no privacy in the emergency open offices. All the discussions of the nurses can be heard in the patient rooms."*

*"The consulting rooms are good. You can't hear anything from those rooms outside."*

Indoor conditions:

*"To keep the noises out, you have to shut the doors. Sometimes patients' rooms are too warm or doctors' offices are too cold. Sometimes you have to open the window, but then there is noise from the construction site."*

*"There is noise from the ventilation and the rooms for consultation and office work are too cold."*

*"The quality of air is superb. After shift I feel myself refreshing unwise in our old facilities."*

*"The ventilation is too powerful, though the temperatures are probably OK. The controllers to adjust temperature are quite tricky. Luckily we got the manual."*

Furniture:

*"The tables in conference rooms are too low. They don´t promote ergonomics. There is no adjustment in office furniture. No ergonomic in sitting work."*

*"You can't take patient bed down enough."*

*"Furniture in waiting lobbies should have been more high-class."*

Distances:

*"Compared to old, ugly, crowded and low hospital the new hospital is spacious. Distances are long from emergency center point of view."*

*"There is space to share. Disadvantages are long distances and getting lost."*

*"Distances are as minimized as possible."*

*"In long corridors all people vanish. You have to wander to find someone to ask."*

Functionality:

*"Pharmaceutical rooms are too small."*

*"There is not enough space. Examination rooms are crowded and in unclear order. In all spaces you can see that staff had no influence on design of spaces, furniture or the way of working."*

*"Our unit is practical and clear. Rooms are spacious and waiting room cozy. We have a lot of equipment, so we run out of storage spaces."*

*"We have not utilized all the functions, equipments and spaces efficiently due to shortage of personnel. It takes time to get everything to run smoothly though the facilities are good."*

*"The rooms are used for a different function to what they were actually designed for."*

The large number of free comments exposes the significance of spaces to staff and the importance to collect feedback. The valuable opinions for the designers and administration of the hospital are now available for the future investments. It is obvious that the design process and tools to enhance the end-user participation are necessary from the first proposal of new premises. The design of sustainable and functional facilities for healthcare requires knowledge of significance of evidence based design, not only the environmental issues, but also consideration of the issues such as safety and better outcomes for patients and staff.

# 5 DISCUSSION

The results of post occupancy evaluation give an extensive overview to the successful design and construction of new facilities. The difference between CAVE-visitors and other staff members in one third of the statements reveals the importance of end user participation. CAVE-visitors were more satisfied with the statements on topics concerning on architecture, acoustics, functionality, comfort, accessibility and usability. Safety was evaluated "good" by both groups.

The post occupancy evaluation defined criteria "good" if the number of responses "strongly agreed" or "nearly agreed" was over 50 %. The quantity of such statements was 86 (81 %). The best assessments (the quantity of responses "strongly" or "nearly agreed" were over 80 %) gained from 49 (46%) statements. Since this study appeared to be the first POE conducted in large scale in the Hospital District of South Ostrobothnia, any comparison to other studies is not conducted, but will one of the objectives for the future studies. The other limitation for this qualitative study is the shortage of statistical analysis. Encouraged nevertheless by this study, there has been one POE survey and two pre-occupancy surveys undertaken to discover the best design decisions for the future hospital facilities.

The large number of other comments exposes the significance of spaces to staff and the importance to collect feedback. It revealed disorders in respect of occupancy and use of new facilities like ventilation, temperature and acoustics. It exposed also the importance of support and management related to functional changes. In addition it revealed important issues, in need of improvement, e.g. car parking spaces and some pharmaceutical rooms.

96 percent of the staff regarded POE-survey "important" or "rather important" and participants prized the opinions to be taken under consideration.

Due to long design, construction and introduction timespan, there have been changes in staff. The issue can be noticed if you study the differences of demographics of participants. The CAVE-visitors were older and had longer working experience. Other staff members were younger and had shorter working experience. New facilities and functions need recruiting and as well replace retirement. As well the healthcare processes change rapidly and the facilities should fit for functional changes for the future.

# 6 CONCLUSION

The latest tool to promote end-user participation in HospiCaseY project was introduced after the completion of the project. Post occupancy evaluation was conducted in October 2013 at the same hospital facilities the project supported. Questionnaires were completed by 182 staff members and 227 patients. The form consisted of demographic information and 106 statements on nine different topics: yards and entrances, architecture, indoor conditions (lighting, acoustics and atmosphere), durability, functionality, safety, comfort (privacy, community and aesthetics), accessibility and usability.

The special interest of this paper is the outcome of the difference between the evaluations of those end-users who had visited virtual environment (CAVE) and the evaluations of other staff members who did not participate in the design process. During the HospiCaseY project 280 end-users, designers and administration visited CAVE. Of those visitors 34 end-users participated in the POE survey.

In comparison CAVE-visitors and other staff members the defined criteria was over 10 percent difference. The number of those statements was 36 (34 %). The CAVE-visitors were more satisfied with the design outcomes than other staff. These statements were from topics on architecture, acoustics, functionality, comfort, accessibility and usability. Overall the results were positive. With defined criteria "good" if the number of responses "strongly agreed" or "nearly agreed" was over 50 percent. The quantity of such statements was 86 (81 %).

After each topic there was an opportunity to make comments. The survey gathered altogether 626 comments. Issues, which gathered most of the comments, were parking, signs, acoustics, indoor conditions, furniture, distances, functionality. Some adjustments and reparations are already executed in the facilities.

This study introduced the benefits of evaluation and established intention to use POE as a systematic tool for all renovations and new construction projects of the Hospital District of South Ostrobothnia. In addition the use of the virtual environment (CAVE) indicates its benefits for better end-user satisfaction.

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# ARTICLE 3

**Use of Virtual Environment and Virtual Prototypes in Co-Design: The Case of Hospital Design**

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# Use of Virtual Environment and Virtual Prototypes in Co-Design: The Case of Hospital Design

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**Abstract:** Co-design is used for improving innovation, obtaining better solutions, and higher user satisfaction. In this paper we present how the use of a walk-in virtual environment and actual-size virtual prototypes support co-design. Unlike in most studies we presented the prototypes to users in an early phase of the design process. This study examines the co-design of healthcare facilities with multi-occupational groups. The practical case examines designing single-patient rooms for an intensive care unit. In this design process 238 participants of different hospital professions evaluated virtual prototypes in three iterative rounds. The participants improved the design by discussing their work practices. The virtual environment situation and actual size virtual prototypes make an easy environment for users to discuss and evaluate the design without any design knowledge. In addition to describing the co-design results we also outline some important issues and guidelines about creating the virtual prototypes and organizing the participants' visits in a virtual environment.

**Keywords:** co-design; virtual prototypes; virtual environment; hospital

## 1. Introduction

For decades there has been a focus on making employees' working environments better for them by including workers' work practice in the design process [1–4]. In order to succeed in this co-operation is needed between the professional designers and the workers who will work in the designed environment or with the designed products. When using co-design, the benefits are, for example, improved idea generation, better understanding of users' needs, and higher satisfaction of users [5]. In addition to long-lasting user participation in the design process (as in Scandinavian participatory development methods, see, e.g., [2,3]) users' involvement for a limited timeframe also gives a strong impact to the design process [6,7].

One problem in users' participation in the design process is users' difficulties in verbally describing their work know-how, as it is tacit knowledge about their work practice [8]. Furthermore, when the participants belong to different disciplines or professions, their underlying assumptions are different, which makes discussion difficult [9]. Another possible problem in co-design is that users could leave their own professional field and become more like designers [10–12]. Thus, they become less concerned with their own occupational needs.

Our study focuses on the multi-occupational co-design, which is an actual topic in co-design studies [13]. As our aim was to make it easy to participate in the process, the solution was to use virtual prototypes. When virtual prototypes are used, their evaluation does not require any special knowledge; instead, the participants can come there with their work knowledge and focus on their work tasks. This works especially well when the virtual prototypes are presented in their actual size,

as in a walk-in virtual environment (VE). In such a case, the users can try their actual work tasks within the designed objects (see, e.g., [8]).

The research question examines what kind of virtual prototype use supports multi-occupational co-design, more specifically, when a walk-in virtual reality solution is employed. In co-design it is important for the users and designers to be simultaneously present in the virtual prototypes since that supports their mutual understanding of the others' work tasks and practices [3,8,14,15]. When discussing the future work environment together, they can find a solution that fits everyone's needs.

The answer to the research question is sought with one actual hospital design case. In it a multi-occupational team evaluate and co-design a single patient room, bathroom and nurse station in an intensive care unit. This Finnish hospital design project was to design the first intensive and intermediate care unit based on a single-patient room concept. Evidence-based design supports the new trend of using single-patient rooms due to multiple benefits on outcomes on care, such as fewer hospital-acquired infections, fewer medical errors, and fewer patient transfers [16]. In addition to construction designers, different kinds of hospital professions also evaluated the design under process.

In our case the end-users participate in the design process only in commenting on tasks by the evaluation of virtual prototypes. By this solution we avoid the risk that is found in intensive co-design processes; in them the participative end-users become, at least partly, designers [12]. In order to avoid participants being expected to have designers' skills, such as understanding the two-dimensional design documents, we use virtual prototypes which are their actual size in a walk-in VE. This kind of immersive VE has advantages in design, such as better spatial perception [17], and it can affect the quality and duration of design reviews [18]. Furthermore, a 3D virtual prototype can be created in an early design phase and then it commits potential users to the design, and the requirements and needs of users can be obtained [19]. A walk-in VE is such an environment which works well for several people to participate simultaneously, so it provides a good opportunity for increasing understanding of others' work practice and their needs for the working environment. This is very important for designing an intensive care unit as various occupations work there with the patient and the environment needs to support all of that work. Our study provides a wider understanding of the possibilities VE gives for multi-occupational co-design.

In this article we first describe the scientific background, which includes both co-design and virtual prototypes. Then we describe our case, the co-design of intensive care rooms in a hospital building. Then we describe two benefits which were reached by co-design with virtual prototypes. These benefits are characterized based on the effect that the hospital staff participation had on the design process. However, we connect them to other researchers' findings. In addition to positive effects we also encountered some challenges within the process. We describe them by giving our solutions of how other co-design processes could avoid those possible problems. Finally, we end the article with a discussion of the results.

## 2. Scientific Background

We present two issues with respect to the scientific background. The first one describes what is meant with co-design. The second one presents tools for co-design, especially such virtual prototypes which can be used together in teams. The latter one is the main issue of this study.

### *2.1. Co-Design*

The term co-creation is based on the idea that consumers are active players who are co-creators of value and co-developers of their own personalized experiences [20]. In addition to consumers, workers are also included in the development of their work tools and environment. This was done for decades based on work democracy, for example, in Scandinavia (e.g., [2,3]). Table 1 characterizes the main idea of user participation in the design process. There are a large number of benefits when co-design is used in the design process (see Table 2). The benefits can be observed based on the actor. The first object is how the co-design changes the design project. It improves the idea generation process and

improves the quality of innovations. The second object is the service user. For them co-design gives a better outcome of the design process, that being the most important issue in the design process. The third object is the organization, which can be either the designer organization or user organization. Co-design improves cooperation between the different groups of people. [6]

**Table 1.** Features of user participation in the design process (based on Kyng [21], p. 52).

| Element | Early Co-Design Process in the 1990s | Recent Co-Design |
|---|---|---|
| *Ideals* | Workplace democracy; Supporting user interest | User involvement; Better systems for all |
| *Users* | Workers as opposed to managers and owners | Non-wage earners, e.g., patients, customers |
| *Settings* | Workplaces | Non-workplaces, e.g., homes |
| *Techniques* | Experimental prototyping; amateur fieldwork | Experimental prototyping; professional fieldwork |

**Table 2.** Benefits of co-design in service design projects (based on Steen [5]).

| Benefits for … Theme | … the Service Design Project | … the Service Users | … the Organization |
|---|---|---|---|
| Improving idea generations | Better ideas<br>Better knowledge about users' needs<br>Better idea generations by bringing together different kind of users. | | Improving creativity<br>Improving focus on users<br>Better cooperation between different people and across disciplines |
| Improving the service | Higher quality of service definition<br>More successful innovations | Higher quality of service | |
| Improving the project management | Better decision making<br>Continuous improvements | | |
| Improving long term effects | | Higher satisfaction of users<br>Educating users | More successful innovations<br>Improved innovation practices<br>Better public relations |

Although user participation in the design process has a long tradition, it varies in what is meant by user involvement in the design process. On one hand, users are considered as informants who can supply facts about work procedures but who have hardly any design knowledge and, therefore, should have little to say about particular design issues [10]. Users stay in their own competence area, and designers' task is to understand them and collect information for the design process [22]. Here this approach is labeled *Designers' move towards users* (Figure 1). On the other hand, there may be user representatives who participate for years in design projects and learn the design practice. Thus, users are expected to participate in the design process and know how designers think and work. Here, this approach is labeled *Users' move towards designers* (Figure 1). In that case, there is a risk that users become professional design experts and neglect the maintenance of their work expertise [10–12]. In addition to dividing the human-centered approaches to actor's roles (whose work is focused and who is asked to be flexible), they can be divided by their focus on either presenting the present situation (*what is*) or future situation (*what could be*) [22].

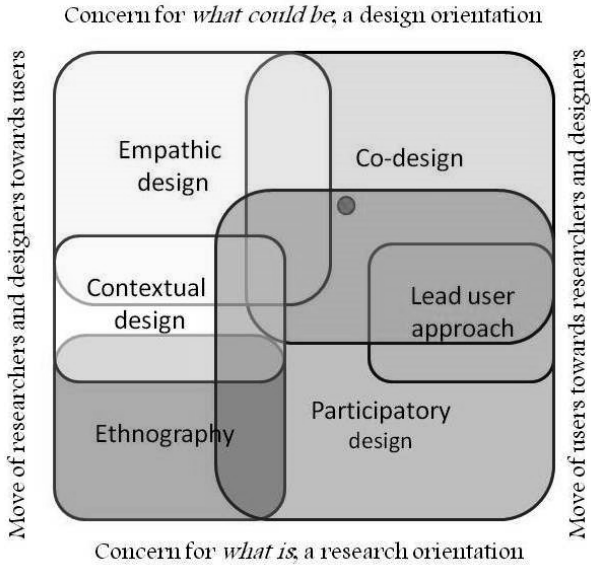


**Figure 1.** Different human-centered design approaches, with different starting points and emphases (based on Steen [22]). The red point in the figure presents where our study is located.

We can locate our study by these two aspects. In the first one, our study locates almost the middle, as the aim is that both designers and users can stay in their own occupational area. The second aspect focuses on the time dimension. In our case, the bases for users' evaluation of the prototypes is the present situation. However, the design focuses on the future situation, i.e., working in the new building, so the main issue in the evaluation of the virtual prototypes is the designed new situation.

Figure 1 describes the alternative user-centered methods. Participatory design and co-design are partly located over each other. In our study we have used the fundamental aspects of participatory design [4], as our study focuses on worker situation and the target is mutual learning between users and designers. However, we also utilize the features of co-design, as the idea of user involvement and better situation for all, and the use of experimental prototyping [21]. The location of our study is marked with a red point in Figure 1.

### *2.2. Co-Design with Virtual Prototypes*

There is a variation of methods and tools which support co-design. A common and successful method is storytelling, as it is how people communicate in their everyday life and it does not require any new tools [23,24]. In addition to verbal description storytelling can use visual elements. In this study we went further towards the visual direction: the use of virtual prototypes so that participants can show their work practices to others.

Virtual prototypes offer a new platform for discussing prospective use and possible improvements. Virtual prototypes include using computers to visualize the prototype, but there is variation on how realistic the visual image is. In addition to visual images, virtual prototypes might also include some functions of the product. The benefit of using virtual prototypes is that they reveal more developing ideas than physical prototypes [25]. Additionally, immersive virtual prototypes have the potential to increase the quality of reviews and decrease the cost and duration of the design process [18]. Furthermore, virtual prototypes are easy to modify so new ideas can be quickly incorporated and new versions can be taken under evaluation [25].

There is a wide variety of virtual prototypes and several methods of using them in co-design. They are connected to each other: technology provides possibilities for co-design and the type of virtual

prototype affects co-design. One end is the use of screen solutions in presenting virtual prototypes, such as avatars in SecondLife [26], whereas the other end is to connect the prototype to a simulation model, such as designing workplace ergonomics with simulated virtual prototypes [27]. Furthermore, virtual prototypes can be presented in a walk-in VE. In such a case, users can try their work tasks with the actual size virtual prototypes (e.g., [25]).

When focusing on the use of virtual prototypes in co-design two issues are important. First one is the size in which the prototypes are presented. If the aim is that the users can try how they could act within a designed environment, the virtual prototypes need to be in actual size. However, if a screen solution, such as SecondLife, is used, then the virtual prototypes are small, and it is only possible to imagine how the work tasks could be done. Instead, actual-size prototypes are presented in walk-in VEs [28], as in the Cave, and in augmented reality, as with HoloLens.

The second issue is how the virtual prototype setting works for multiple people, which is needed in a co-design situation. When the aim in co-design is that mutual communication in the organization gets better, it is required that during the co-design process several people can be simultaneously in the same room evaluating the virtual prototypes and presenting to others how they would perform their work tasks within the prototypes. For such needs only a walk-in VE works, as the participants see the same image (i.e., the same virtual prototypes) and each other. Thus, they see what others are doing but also their nonverbal signs (gestures and expressions) during the co-design session. That is not possible with most augmented reality lenses; for example, HoloLens is just for one person.

In their review Kim et al. [13] classified 150 journal papers (2005–2011) in the field of the built environment concerning the use of virtual reality and virtual environment. Collaborative use of VR systems was used in 36 articles (26%). Kim et al. also predicted that multidisciplinary collaboration will become a standard in built environments [13].

When using virtual prototypes, the level of fidelity for prototypes needs to be decided. High-fidelity prototypes look like final products with a large amount of detail, whereas low-fidelity prototypes are insufficient, like sketches and virtual prototypes without texture or other details, for example. There are opposite views as to what level of fidelity works best in user evaluation. On the one hand, high-fidelity prototypes help professionals, and even non-professional participants, perform accurate design reviews [18]. On the other hand, when low-fidelity prototypes are used, the non-technical users have more space to evaluate and develop the presented prototypes [25,29]. In our case we used both high- and low-fidelity prototypes.

## 3. Research Methods and the Case of Hospital Design

The research method of this study is action research. The practical problem, which we attempted to solve, is the design of a new intensive and intermediate care unit. The theoretical knowledge that is utilized in solving the practical problem is co-design and virtual prototypes. For the practical case, this theoretical basis calls for nurses and other hospital workers' presence during the design process. In addition to using the theoretical knowledge in solving the practical problem, practical problem-solving is used to attain theoretical knowledge.

In the health care sector, it is realized that workers', i.e., nurses and doctors, participation in the design process is important for supporting innovations (e.g., [30]), since new co-design languages to facilitate cross-cultural communication are valued [11]. Our study utilizes these positive effects on co-design within the health care sector.

This study was carried out within a hospital design and construction project (2014–2018) in Seinäjoki, Finland. This hospital was the first hospital in Finland with single-patient rooms in intensive and intermediate care units. Single-patient rooms were designed since studies prove that this solution provides several benefits, such as fewer hospital-acquired infections, fewer medical errors, improved patient sleep, improved patient privacy and confidentiality, and fewer patient transfers [16]. The design project utilized multiple tools to support the hospital staff's participation in the design project.

The single patient room concept will change the work and work processes [31]. The intensive care room, the intermediate care room, bathroom, and nurse station were chosen to be designed. These rooms were chosen to co-design with the hospital staff, because of the number and the significance of the rooms. The total number of patient rooms was 24 and they formed the core of the new unit. The size and the form of the rooms, as well as their mutual situation, needed to be ensured for the changeover to single-patient rooms. Co-design virtual prototypes were chosen as the methods and the tools to support the design process. The hospital staff's role in the co-design process was to evaluate and comment on the draft which the architect team had designed. By using actual-size virtual prototypes, the hospital staff could try how they would work in the designed environment. Additionally, the idea of co-design was that multiple staff members participated simultaneously as they could discuss several work processes that need space and equipment around the patient bed. The hospital staff members were supported by their colleagues which made their comments more powerful.

In this section of the research methods, we first present what kind of VE we used in presenting the virtual prototypes. Second, we outline the process of presenting and evaluating virtual prototypes. Third, we present what kind of users visited the VE and evaluated the prototypes. Finally, we outline how the data was analyzed.

### *3.1. Walk-In VE*

For making simultaneous participation possible the virtual prototypes were presented in a walk-in VE. It is a room comprised of three walls, a ceiling, and a floor. The fourth wall was open in order to allow access into the space (Figure 2). The measures of the walls are 3.0 × 2.5 meters each. Images generated using computer graphics cards were projected onto these surfaces, which, when viewed through stereoscopic glasses, were transformed into a 3D full-scale environment. The most important property of a walk-in VE is its scale, i.e., the ability of visitors to perceive the environment as almost real. Visitors can move to some extent within the space itself and travel longer distances (that means seeing other parts of the building) with the help of a 3D mouse.

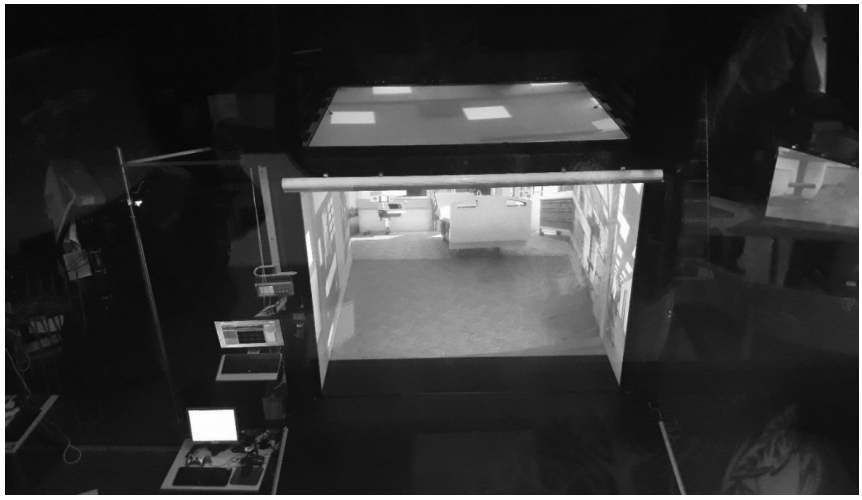

**Figure 2.** The walk-in VE is situated in a bigger room. There are projectors for each wall.

The software used in this project was TreeC Technology´s VR4MAX. The virtual prototypes were created by the staff of virtual reality laboratory of Seinäjoki University of Applied Sciences, Finland. This was also the venue in which the prototypes were presented and evaluated. To help the navigation in the model the virtual prototypes were fixed on the floor level, so flying was impossible. Additionally, going through walls was restricted, so it was impossible to get out of the virtual prototype. The third

prototype included some functionality, such as sliding doors and the possibility to move medical ceiling-mounted joints.

### 3.2. Presenting the Virtual Prototypes

The designing of the new hospital unit required virtual prototypes, which included the two single-patient rooms, bathroom, and nurse station. The final version of the unit plan was created in three rounds of virtual prototypes. Between the rounds the new prototypes were modified based on the users' discussions of the earlier one.

The precision and fidelity of virtual prototypes increased round by round. The first and second virtual prototypes included only the patient bed and ceiling-mounted booms. The requirements for room size and shape, and furniture and equipment placement and quality were attempted to be discovered with these virtual prototypes from participants. Low-fidelity virtual prototypes produced discussions of missing furniture and equipment and their number and placement. The participants evaluated the placement of furniture and the shape of the rooms relating to the visibility of the patients. Additionally, the absence of windows in these earlier virtual prototypes caused a discussion of the importance of natural light and views of nature.

The third virtual prototype included all needed furniture, equipment, and accessories. The virtual prototype contained a window and a landscape painting to add comfort. The feedback of this last virtual prototype from participants focused on placement and quality of furniture, equipment and accessories.

The VE visit started with presenting information about the project, the location of the VE, the duration and the objects of the visits. The participants were informed that the rooms were incomplete, so their comments were needed for their future design. Additionally, information pertaining to videotaping, photographing, and recording their visits was provided. Before the actual design session, the researcher introduced the project group, demonstrated how the work would happen in practice in the VE, and explained outlines for the virtual prototype presentation. Participants were told that they could interrupt and comment anytime during the presentation.

The project group had planned the route for the virtual prototype presentation. That included a visit in an intensive care room, a bathroom, a nurse station, and then into another intermediate care room and a bathroom. The architect presented spaces with the same description to all the groups. The planned route took approximately 15 min. After that groups could return to the virtual rooms they wanted to evaluate more closely. All the time the participants could interrupt and ask for details or comment. The visit in the virtual rooms lasted between 30 and 40 min.

The setting of a VE visit is presented in Figure 3. The distribution of assignments in project group was the following:

- *Architect* presented the virtual rooms and answered comments on the technical and design side.
- *Navigator* guided in the viewing of the rooms and used the 3D mouse.
- *Researcher* opened the conversation if needed, asked for details and grounds for changes, gathered the comments and change requests.
- *Project worker* answered comments on the functional side.
- *Photographer* took videos and photos.

The evaluation of the rooms was completed in three rounds. The researcher gathered the comments during the VE visits. The project group discussed the change propositions and evaluated them. The ones that were evaluated to increase the prototypes or which had substantial reasoning, were taken for further design.

**Figure 3.** The setting of a VE visit.

In addition to mutual discussion the participants were asked to complete a questionnaire in which they could analyze the properties of the spaces more systematically as well as evaluate the virtual environment experience. The aim of the questionnaire was to make sure that all comments and evaluation would be brought together. For this study only a part of the questions was analyzed. That part included statements which dealt with two issues: first, how good the co-design in VE was, and second, what kind of feeling the VE gave to the participants.

### *3.3. Users Who Visited the VE*

The VE visits took place in the spring of 2015. The timetable and number of groups and participants are shown in Table 3. There were 47 multi-occupational groups altogether. There were approximately 4–6 participants in each group. In one group there was only one participant and in few groups more than six participants. The total number of visitors was 238.

**Table 3.** The timetable and number of groups and participants.

| Dates | March 2015 | April 2015 | May 2015 | All |
|---|---|---|---|---|
| Groups | 14 | 18 | 15 | 47 |
| Participants | 61 | 89 | 88 | 238 |

Most of the participants (157) visited the VE only once, whereas one third of the participants (81) attended two or more rounds. The largest occupational group was nurses: 67% of participants. The rest were physicians, designers, cleaners, technicians, health and facility managers, students, and other healthcare professionals. Most of the participants were women, 79% in all. The median age was 45 years ranging from 24–65 years, calculated from those participants who disclosed their age. However, 26% did not divulge their age. The work experience ranged from 1–40 years and the median was 19 years.

The groups varied by occupation, but there were one or more nurses in all groups. Different occupational groups highlighted the requirements of their own profession and work set for the spaces.

The requirements were partly similar, but partly contradicted each other. There were some participants from other hospitals, too, and this brought into discussion differences between hospital cultures.

In addition to discussion of virtual prototypes there were discussions of visibility, work processes, and the number of nurses. The method of working was changing due to single-patient rooms. Additionally, the conversations in the VE included issues that cannot be evaluated in VE but are very important for design, like floor materials.

### 3.4. The Analysis of the Gathered Data

Two kinds of data were used for this analysis. The first one was a questionnaire, which the participants answered just after their VE visit. This data was analyzed statistically. The questionnaire included seven statements about the functionality of the groups' co-design within the VE visits and the feeling in being in the VE. It was calculated how many participants agreed to the statement. This data outlines participants' (i.e., hospital staff's) opinion of the co-design with virtual prototypes.

The second one is the discussion during the VE visit and the development of virtual prototypes. These data are notes which the researcher made based on her observation of the VE visits. Although she made them during the actual VE visit, they were also videotaped and it was possible to check from the video what actually happened.

## 4. Results

The results consist of three issues. The first one outlines the general picture of participants' views of their visits in the VE and their participation in co-design. This part is based on the analysis of the questionnaire. The second issue focuses on the benefit of organizing co-design sessions with virtual prototypes. The result is that hospital staff's work practice become visible to designer team and with it they can create better designs. The third issue is the benefit that hospital staff discussed the risks which the new design might include, and they co-operatively found solutions to overcome the risks. In the next sections we present the three issues with examples from the empirical data.

### 4.1. General Picture: Useful Participation

Just after the VE visit, the participants filled out the questionnaire about the VE and the co-design process. The results show that they found the co-design very useful, as presented in Figure 4. The questionnaire included seven statements, which dealt with the functionality of the co-design with virtual prototypes. The statements were evaluated by how much the participants agreed with them. This was done with a five-point scale from "totally agreed" to "totally disagreed". Figure 4 includes the participants' evaluations of the statements after all three VE visit rounds. The evaluations of the rounds are presented together, although the virtual prototypes and their fidelity varied.

The questionnaire included five statements, which dealt with the following:

- Participation was useful (totally and partly agreed 96%);
- Designing in groups was a useful method (totally and partly agreed 95%);
- In discussion, my opinion was taken into account (totally and partly agreed 85%);
- Commenting was easy (totally and partly agreed 92%); and
- Active participation was easy (totally and partly agreed 89%).

Additionally, the questionnaire included two statements, which focused on the immersion of the VE. In the evaluation they were also quite highly agreed:

- I felt like being inside virtual rooms (totally and partly agreed 96%); and
- Space was real and natural (totally and partly agreed 94%).

The participants' general feeling was that participation in co-design with virtual prototypes was useful. This evaluation is done based on the answers in the questionnaire.

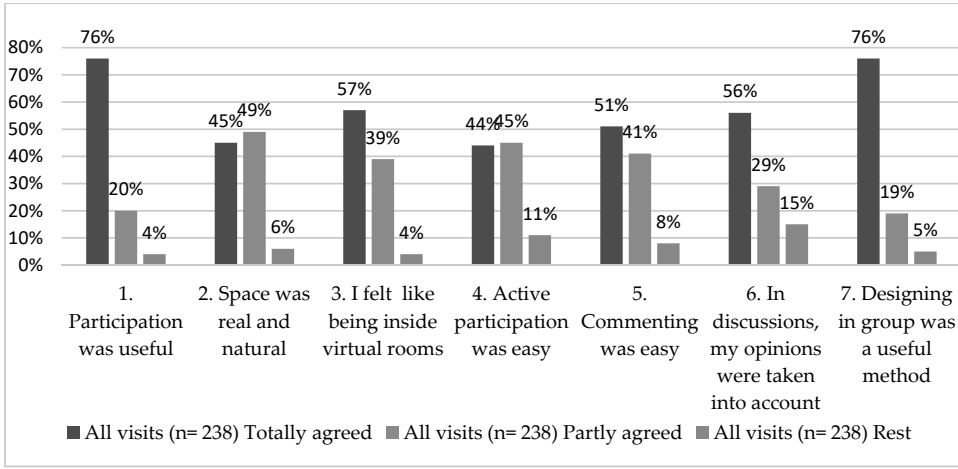


**Figure 4.** Results of the questionnaire evaluating co-design and virtual environment. ("Rest" includes answers "don't know", "partly disagreed", "totally disagreed", and missing cases).

### *4.2. Benefit 1: Professionals' Work Practice to Designer Team*

The benefit of virtual prototypes is to support communication within the design teams and the users of the design outcome [29]. Especially when low-fidelity prototypes are used, the non-technical users have more space to evaluate and develop the presented prototypes [25,29]. The use of virtual prototypes gives hospital staff a possibility to stay in their own professional field without trying to act like professional designers [8].

In our hospital design case, the target was to support hospital staff's participation by discussion and finding a good solution that fits every situation in which the room will be used. The idea was that the actual size virtual prototype gives a possibility to discuss together how alternative professional groups will work there. The first version of the prototype for hospital staff to evaluate is presented in Figure 5. The prototype presents a part of an intensive care unit which includes a nurse station for two nurses and two-single-patient rooms which both have their own bathroom. One issue that was used for improving the discussion was that, in the first evaluation round, the presented virtual prototypes were somehow low-fidelity. The prototypes were missing many detailed objects and wall textures. The aim of getting the participants to discuss together was fulfilled excellently in our case. In the VE visits the participants brought up many issues that reflected their concerns for future facilities.

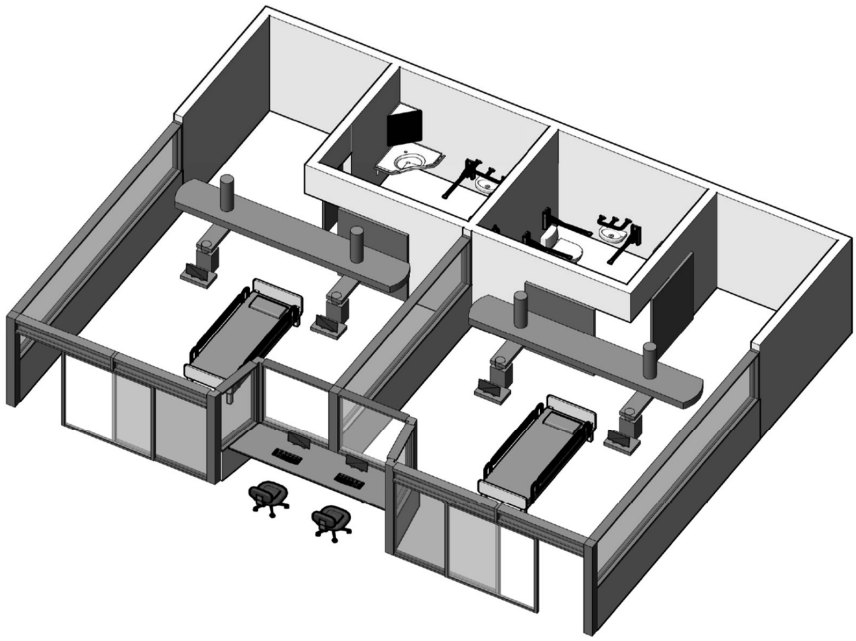

**Figure 5.** The first prototype.

The first issue was the size of the rooms. The virtual prototypes appear to be adequate in size but whether this proves to be the case in a work situation depends on how full of equipment and staff the room is in a critical situation. The participants listed the missing furniture and equipment and presented their position related to the patient bed. Additionally, participants listed other items needed in the room like a sink, storage units, armchairs for relatives, and accessories. Open floor space around the patient bed is very important. Ceiling-mounted booms for respirators and other equipment and ceiling mounted patient lift and movable objects were evaluated to be practical by sparing floor space and avoiding wires on the floor.

The second critical issue in patient care is the transportation of a patient with all the equipment. The doors should be wide enough. Usually many staff members participate in the process. From that point of view the location of the bathroom was very critical. First, a patient is moved from the bed to a stretcher or a wheelchair with all the necessary equipment and then transported to the bathroom. The route should be accessible and clear. The approved location for the bathroom was found in the third virtual prototype (Figure 6.).

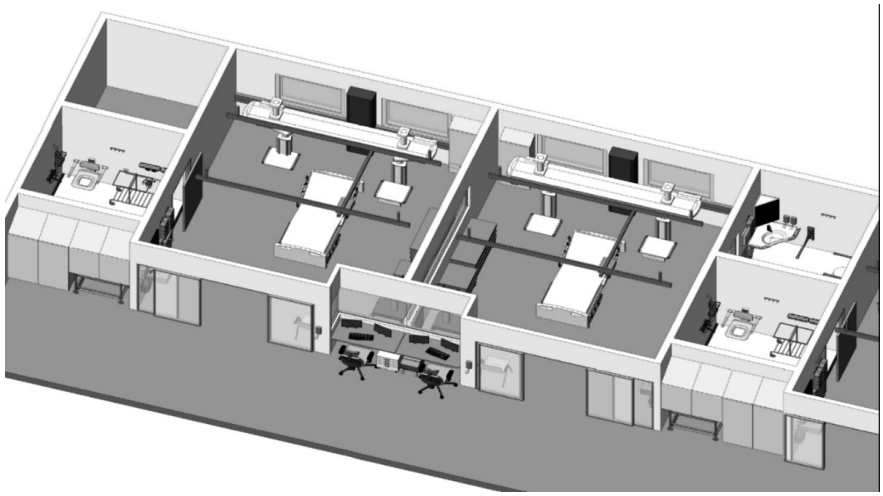

**Figure 6.** The third prototype.

The third issue was that it was easy to comment on the virtual prototypes for participants. All the participants had the same view and it was possible to show the item that needed to be changed. Nurses and other hospital professionals could use their professional language describing their work processes and space requirements. It was easy to find shortcomings as well. As the groups were multi-occupational the different requirements concerning the rooms were discovered and discussed.

The fourth issue discussed was the request for the design of the whole new unit with virtual prototypes. It is important to see how different rooms are situated in relation to each other and the distances between the rooms. During a work shift the staff must go to a storage room, a utility room, a pharmacy room, a restroom and nurses' office. The layout of the unit should be designed so that it saves the steps taken during a shift. It was impossible to design the whole unit during the project, but all the ideas about layout were driven forward.

### *4.3. Benefit 2: Discussions of Risks and the Solutions*

In co-design the benefits for users are getting higher quality design outcomes and, in the longer term, higher satisfaction [5]. For reaching these goals one part is to discuss and solve the possible problems which users see when they evaluate the design. In our case the multi-occupational teams discussed the possible risks when the virtual prototypes were observed and evaluated. In these situations, two possible risks were commonly discussed. The first of them is how the nurses get assistance, and the second one is the limited quantity of natural light in the rooms.

The changeover to single-patient rooms was the greatest challenge in the design process, because it causes changes in work processes which also highlight the risks in care to be handled. The old unit was multi-bedded. Patients were separated by curtains, so they were near each other. It was easy for nurses to ask for assistance from other nurses. The new unit with single-patient rooms highlighted three risks to solve. They are assistance, visibility, and audibility. The nurses were concerned how to get assistance when they are working in different rooms. They were concerned that they cannot see each other and the patients and hear the patients. Similar concerns can be found in earlier studies of transitions to single-patient rooms [31].

In our study virtual prototypes were used for being sure that it was easy to get assistance by having visibility between the rooms. The visibility was needed for nurses to see their patients and other nurses. Audibility was also needed, so that nurses could hear what was happening, e.g., how the patient was breathing or if other nurses needed assistance. The solution was studied with virtual prototypes. The walls and sliding doors towards the corridor were made of glass providing visibility.

Additionally, the nurse station between two patient rooms provides good visibility to these two rooms. However, privacy was also needed, so that the patients could not see what was done to other patients or even who the other patients were. The minimum height of the window between two patient rooms was measured so that a patient lying in the bed could not see to the other room.

In discussion about the risks the second issue was windows and natural light in patient rooms. Studies prove that natural light supports patients' healing [16]. During the design occurred that some patient rooms are not provided with windows. The proposed solution was to design the layout so that most of the patient rooms will have windows and skylight windows in the corridors.

In our case of designing a hospital intensive care unit, the hospital staff discussed their concerns for when the unit planned to change from multi patient rooms to single-patient rooms. The discussion happened in a walk-in VE with virtual prototypes in multi-professional teams. The hospital staff's concerns were taken seriously, and the solutions were found.

## 5. Practical Guidelines for Organizing VE visits

In our study we used a walk-in VE for multi-occupational co-design. The hospital staff participated in the design process by evaluating the virtual prototypes and improving the design. During the co-design a high number of VE visits with 238 participants were organized in a short period. The three rounds of VE visits and development of the virtual prototypes were carried out in three months. As the timetable was tight and the number of participants high, we needed to plan the VE visits carefully. Within organizing the VE visits we made practical findings and we want to share our knowledge to others who use virtual prototypes in co-design.

*Guideline 1: Prototype.* The participants expressed the wish to design the whole area. In larger layouts a bird's eye view is helpful to comprehend the whole design, although it increases the risk for simulation sickness [32]. In our case the virtual prototypes were modelled so that the floor level was fixed (flying was impossible); it was also impossible to get out of the prototype. Still, some of the participants had dizziness and inconvenience in balance and they did not like the visit due to those symptoms. These problems occurred when using automated navigation in which the layout was presented with a route that was decided beforehand. As it caused problems to some participants, the speed of the tour was too high.

In addition to the whole landscape the outfit of the prototypes under evaluation needs to be decided. An important point is the level of fidelity, since it affects the users' evaluation [25,33]. In our case, the first prototypes were low-fidelity and the participants then focused on the missing elements of the prototype. The last prototype was higher fidelity and then the focus was on the details, such as the placement and type of furniture and accessories. As de Casenave and Lugo [18] claim in their article, high-fidelity prototypes help professionals, and even non-professional participants, to perform accurate design reviews. Furthermore, with this prototype less improvements were presented.

*Guideline 2: Improving the prototype.* In using virtual prototypes in co-design, the idea is that the prototypes are improved between the evaluation rounds. The first step is to analyze the users' comments and improvement ideas and then decide which ones will be taken to the next evaluation round. After that is the implementation task, which depends on the used VE environment and the implementation tools how quickly the changes are possible to be made. In our case, some weeks between the evaluation rounds was too short a time and there was not enough time to test the improved prototype before the next VE visit. The final task before new VE visits is testing the new virtual prototype by the project group.

*Guideline 3: Groups and rounds.* One of the main benefits of co-design is to increase the mutual understanding of workplace work [5]. To reach that, multi-occupational groups need to be organized. In our case the groups were formed based on the staff's working timetable and ensured that several different occupational members participated in each group. Another solution could be on the bases of work processes. The other issue about groups that must be decided is how many evaluation rounds the same persons take part in. In our case, most participants participated only once. The participants

who participated two or three times commented that it was easier to concentrate on evaluating the virtual prototypes when the VE was familiar. However, if the same persons participate in too many evaluation rounds, it is possible that they become more like designers [12].

*Guideline 4: Navigation*. The navigation arrangements should be considered carefully, since some VE visitors like to use the navigation tool (3D tool), whereas others avoid using it, and that does not depend on how difficult they find the use of a 3D tool [34]. It is recommended that the navigation task is given to a supported person, not to anyone from the evaluation group [35]. In our case, in most of the VE visits the navigation was done by an experienced navigator and that would have been a good solution for all the VE visits.

*Guideline 5: Duration of the VE visit.* When deciding the duration of the VE visit two kinds of issues need to be considered. For the participants the VE visit is a difficult task that demands concentration, so the visit must not be too long. A VE visit with new technology requires learning from the participants. Furthermore, the evaluation task done in a multi-occupational group is also a challenging task. We used approximately 30–40 min per group in VE.

The other issue that needs to be considered is the cost of the VE visits. The visits take many working hours. In addition to the work of the design project team the participants use their working time for the evaluation task. In our case that part was almost 300 h, as there was some distance from their workplace to the VE laboratory. The other part of the costs is the use of the VE laboratory. However, the costs of VE are coming down as more technological options come to market.

## 6. Discussion

We presented an action research study in which the practical part is a real hospital design case. In our case the design target was to move from a multi-bedded intensive care unit to single-patient rooms. The new wing to the hospital building was under design but also the nurses' work practice was changing. Single-patient rooms are known to have many benefits, however, there were also many risks [16,31]. When the design plan was under multi-occupational evaluation with using virtual prototypes, the possible risks were discussed and solutions were found. The participants evaluated the VE visits and valued co-design high, as presented in Figure 4. The design was done in 2015, then the new building as built and taken into use in 2018. The result will be evaluated in the autumn of 2019.

Our study outlines co-design, which Steen [22] localizes to human-centered design approaches, as shown in Figure 1. The location of the approaches is presented by two dimensions, which are:

1. The dimension of whose profession is dominating (designers or users); and
2. The time dimension from present situation (what is) to future possibilities (what could be).

Our study was located quite in the middle, just in the time dimension and a bit more to the future. Furthermore, Steen's figure includes alternative methods of human-centered design approaches [22]. Our study belongs to co-design, but also takes elements from participatory design. The concept of co-design is more focused on consumers' role on design [20], whereas our case focuses on workers' participation, as is done in participatory design [3,4].

Our study proves that discussion between designers and multi-occupational users can happen in a neutral space, in which neither profession dominates. There is a large risk in co-design that users become designers if the co-design process is long and the method requires design knowledge [12]. We created a neutral space for discussion about the design with virtual prototypes which are presented in a walk-in VE. In such a situation users do not need to understand design methods or tools; instead they can focus on their work tasks and present them to designers, who can include those needs in the design process.

When virtual prototypes are used one issue that needs to be solved is the level of fidelity of the prototypes. Some studies (e.g., [18]) claim that the higher the fidelity level, the easier it is for users to evaluate the prototype. Some other studies (e.g., [25,29]) claim that lower fidelity gives more freedom to users to evaluate the prototype, as the high-fidelity prototypes might seem to users that they are

ready designs, not under development anymore. In our study we used both high- and low-fidelity prototypes. In our case, during the first two VE rounds the virtual prototypes were of lower fidelity, e.g., the texture was missing, whereas in the third VE round the virtual prototypes were of higher fidelity. In our case, both the high- and low-fidelity virtual prototypes supported the mutual discussion in the VE visits.

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# ARTICLE 4

**Nurses' Participation in the Design of an Intensive Care Unit: The Use of Virtual Mock-ups**

Jouppila, T. and Tiainen, T

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# Nurses' Participation in the Design of an Intensive Care Unit: The Use of Virtual Mock-Ups

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**Abstract**

**Background:** Co-design with multiple tools is useful when end users' knowledge is important, especially when designers work with people unfamiliar with design. Many studies have highlighted the importance of nurses' participation in design, and such participation requires the development of techniques and tools to facilitate collaboration. This article analyzes how nurses participated in designing a general intensive care unit in a walk-in virtual environment (VE) and examines how their work-related knowledge can be transferred to the design process of spaces. **Method:** In this action research study, the design process was conducted by using virtual mock-ups, which were evaluated by multi-occupational groups in a walk-in VE. Nurses were the largest occupational group. Their work processes were under modification, since existing multi-patient rooms were being redesigned as single-patient rooms. The design of single-patient rooms was performed in three iterative cycles in the walk-in VE. **Results:** The nurses could specify their requirements in the walk-in VE, and their suggestions were incorporated into the architectural design process. The nurses were satisfied with their role in the design process. **Conclusion:** Co-design with virtual mock-ups in walk-in VE is appropriate when designing new healthcare facilities and when the opinions of workers are important. Virtual mock-ups in walk-in VE can be used collaboratively, facilitating simultaneous feedback from multiple users. Virtual reality (VR) technology has evolved, and changes can be made rapidly and at a lower cost. Another advantage of VR is that it allows one to design larger spaces, thus providing larger layouts of facilities for evaluation.

**Keywords**

co-design, virtual mock-ups, virtual environment, single-patient room, intensive care unit, nurses

Many studies state that it is important to include nursing staff in the design processes of healthcare facilities (Berry & Parish, 2008; Redden & Evans, 2014; Sundberg et al., 2017). Nurses possess knowledge that is required in the process, as they know their work practices and the space needed for different tasks. However, it is quite common that nurses have no experience in designing healthcare facilities, and the chance to participate may occur only once in a lifetime

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(Thompson et al., 2012). Although it is not always obvious that nurses should be included in design groups, their participation has been evaluated to be highly important (Cesario, 2009; Keys et al., 2017; Redden & Evans, 2014; Thompson et al., 2012), even in the early design phase (Elf et al., 2016). However, their participation poses many challenges. It is hard for nursing professionals to explain their requirements to the design professionals due to a lack of knowledge regarding the design and construction processes, and nurses' skills in reading two-dimensional drawings are limited. Furthermore, there are difficulties in communication between nurses and designers due to different vocabularies (Cesario, 2009; Reno et al., 2014). The participation of nurses requires the development of techniques and tools to facilitate collaboration.

Multiple visualization tools have been used to help healthcare professionals. Such tools include full-sized mock-ups, building information models (BIM), and other modeling programs which support the end users' understanding of space better compared to drawings (Reno et al., 2014; Wingler et al., 2019). "Seeing the design as built" can prevent shortcomings in repetitive spaces, like patient rooms, and the consequent need for post-occupancy renovations (Reno et al., 2014). Cesario (2009) adds the need for knowledge of design issues, familiarity with technical terms, and basic information of evidence-based design (EBD) to support the nurses' participation in design.

Collaborative design methods with multiple tools are useful in cases where the knowledge of end users is important. Co-design is an advantageous approach for designers and people who are not used to working together. Co-design refers to the phenomenon of designers and end users without any design education working together in the design development process (Sanders & Stappers, 2008). The participants bring their expertise to the process, and the designers and researchers provide tools to express ideas and comments. Participatory design (PD) and co-design have been used successfully in the design of systems which need the knowledge and practice of users. PD and co-design have been used in the design of healthcare facilities and processes (Elf et al., 2016; Reay et al., 2017; Watkins et al., 2008).

Virtual environment (VE) and virtual reality (VR) have been utilized in architecture and the design of new healthcare facilities (Dunston et al., 2007, 2010; Fröst & Warren, 2000; Wahlström et al., 2010; Wingler et al., 2020). The VE or VR platform impacts how effective virtual mock-ups are in terms of evaluating functionality or collaborating with users. Platforms vary from desktop computer monitors with a 3D stereoscopic effect to true-stereo 3D platforms like walk-in VE and head-mounted displays (HMDs) Kim et al., 2013). Collaborative design can be done in walk-in VEs (Bullinger et al., 2010; Fröst & Warren, 2000).

In this article, we study how nurses' work-related knowledge can be transferred to the design process of a healthcare facility. This study is one part of an action research study on the actual renovation and enlargement of a hospital. In this practical design process, single-patient rooms for a new general intensive care unit (ICU) were designed with co-design as a method. The nurses visited the walk-in VE and evaluated the virtual mock-ups in multi-occupational groups. There was a total of 238 participants, and the largest participant group was nurses (there were 160 nurses, i.e., 67% of the participants). The design was processed in three iteration cycles, and the virtual mock-ups were redesigned after the groups' feedback before the next cycle. This study demonstrates that co-design with virtual mock-ups works well, as the design professionals understood the nurses' evaluations and suggestions for improvement. The results reveal that the changes recommended by the nurses were implemented in the new virtual mock-ups, and the nurses were satisfied with the design method and the tool.

## Scientific Background

The scientific background of the study consists of two elements. The first focuses on the use of co-design for architectural purposes and designing spaces. The second focuses on using VE and VR in design. Designing and constructing healthcare facilities is expensive, and shortcomings in design and construction cause expenses and sometimes require changes in newly built

facilities (Reno et al., 2014). Collaborative design is a core competence of co-design, and VE and VR show the design in visual form, thus enabling nondesigners to evaluate the design from their own professional and experiential viewpoint.

*Collaborative design is a core competence of co-design, and VE and VR show the design in visual form, thus enabling nondesigners to evaluate the design from their own professional and experiential viewpoint.*

## Co-Design

The roots of co-design lie in PD, a Scandinavian approach to design which emphasizes the collaboration of designers and end users in a process to improve the quality of working life (Halskov & Hansen, 2015). End user participation in the design of new information technology (IT) systems has been especially significant (Bjerknes & Bratteteig, 1995; Kensing & Blomberg, 1998). End user participation results in increasing knowledge, developing realistic expectations, reducing resistance to change, and giving opportunities to participate in decisions that are likely to affect the end users' work (Bjerknes & Bratteteig, 1995). PD has expanded from IT development to other fields—such as product development, space design, and architecture—and new approaches to involve end users have evolved (Halskov & Hansen, 2015; Kujala, 2003). Design teams consist of people with different backgrounds, experiences, and interests. In space design and architecture teams, not all the participants have a background in design, but they do have experience in their own discipline (Sanders et al., 2010). Co-design teams will become more diverse in the future (Sanders & Stappers, 2008). Furthermore, architecture and planning are the last of the traditional design disciplines to show an interest in exploring new design spaces, primarily in the design of healthcare environments (Sanders & Stappers, 2008). Co-design allows end users to stay in their own field of expertise.

PD has been successfully used in designing workplaces (Davies, 2004; Johansson et al., 2002). Various tools and design artifacts (video cards, board games, scenarios, and interactive digital VR visualizations) have been utilized in workshops (Johansson et al., 2002). In addition, full-scale modeling of life-size mock-ups and 3D computerized design and visualization have been used to allow individuals and groups to take part in design and provide communication (Davies, 2004). Together with physical mock-ups, PD has been used in the healthcare sector both in design and simulation (Watkins et al., 2008). Visualization tools and techniques promote a practice where designers can learn from the participants' work and where both technology and the work organization are the focus (Kensing & Blomberg, 1998). Visualization helps the participants take an active part in design.

## VE and Virtual Mock-Ups

The focus of this study is on full-size virtual mock-ups for collaborative use. VE, VR, and virtual mock-ups have been used in design projects (Bullinger et al., 2010; Dunston et al., 2007; Fröst & Warren, 2000; Wahlström et al., 2010). Walk-in VEs with full-size virtual mock-ups are used by workers to show designers how they carry out their work tasks. Walk-in VEs can be a computer-assisted virtual environment (CAVE) or other screen-based projection. Full-size virtual mock-ups can be evaluated by HMDs as a platform (Heydarian et al., 2015; Wingler et al., 2020; Wingler et al., 2019), but an HMD is impractical for collaborative evaluation, as the collaboration space is collocated and remote, and the participants are unable to see other users (Cordeil et al., 2017). Furthermore, other participants cannot see others' gestures or make eye contact (Ellman & Tiainen, 2019).

CAVE technology has been used in the collaborative design of laboratory layouts (Fröst & Warren, 2000). The results show VE provided users with a method where they could formulate, analyze, test, and realize their ideas (Fröst & Warren, 2000). Furthermore, a virtual mock-up of a patient room with interactivity elements has been built where individual healthcare practitioners could perform a variety of actions, that is, rearrange furniture, adjust lighting, and change the size of the room

(Dunston et al., 2007, 2010). Dunston et al. (2007, 2010) suggested using VR mock-ups instead of physical mock-ups because they are less expensive and easier to modify. In one study, actual hospital ward rooms were contrasted with patient rooms modeled in CAVE (Wahlström et al., 2010). CAVE enabled individual end users, patients, and nurses to express their perspective and expertise in the design of patient rooms, although some limitations were observed (Wahlström et al., 2010). Wahlström et al. (2010) argue that "VR systems might contribute to a transition from an expert-based hospital design to a more democratic and user-based one" (p. 209). Comparing "user-real product" and "user-virtual product" interaction individually and in focus groups using a PD approach, researchers claim that VR provides a tool to evaluate the usability of the virtual product interface and gives the end users a communication channel to involve themselves directly in the design process as co-designers (Bruno & Muzzupappa, 2010, p. 255). VR and virtual prototypes provide more development ideas for furniture compared to physical ones from nontechnical consumers (Tiainen et al., 2014). Bullinger et al. (2010) combined architecture, user-centered design, PD, and an immersive VE in their studies on designing a new laboratory building. The use of user-centered design with a VE increases quality and performance in building and construction projects (Bullinger et al., 2010).

Physical and virtual mock-ups have many mutual features. They can be used to design spaces and provide simulations. They can be of different levels of detail, they provide immersion, and they can be evaluated in groups or individually. Furthermore, changes in mock-ups can be costly and time-consuming (Watkins et al., 2008). VR technology has evolved thanks to 3D architectural applications, BIM, and game engines, and changes can be made rapidly and at a lower cost. Another advantage of VR is that it allows one to design larger spaces than just a few rooms, thus providing larger layouts of facilities for evaluation.

## Method and Implementation of the Study

This action research study was performed within an actual hospital design project (2014–2016) in Seinäjoki, Finland. The design of single-patient rooms, private bathrooms, and the nurses' station was performed in three iterative cycles in walk-in VE. The chosen method was co-design, in which designers and end users without any design education work in collaboration. As visualization helps end users to understand the design, virtual mock-ups were chosen as the tool. The new ICU will have six intensive care rooms and 18 intermediate care rooms, including two isolation rooms. The target of the study was to benefit the forthcoming construction project (2016–2018) of a new intensive and intermediate care unit by providing drawings of the most critical spaces concerning the work of nurses and other medical staff.

### *Walk-In VE*

In the design project, walk-in VE provided the surroundings for the collaborative design work and face-to-face interaction. Small groups of four to six participants saw presentations of the designed mock-ups. Two intensive care rooms, two intermediate care rooms, private bathrooms, and the nurses' station were modeled in VE. The participants could then evaluate the designs of the mock-ups and give feedback from their professional view.

The VE used in the project was CAVE. CAVE is a room comprised of three walls, a ceiling, and a floor. The fourth wall is open to allow access into the space. The walls are each 3.0 m × 2.5 m (9.84 ft × 11.48 ft). The floor space is 9 $m^2$ (96.84 $ft^2$). Images generated using computer graphics cards were projected onto these surfaces, which were transformed into a three-dimensional full-scale environment when viewed through stereoscopic glasses. The most important property of a walk-in VE is its scale, that is, the ability of visitors to perceive the environment as almost real. Visitors can move to some extent within the space itself and travel longer distances with the help of a 3D mouse. The software used in this project was TreeC Technology's VR4MAX (Release 7.80). The venue for the studies was a virtual laboratory at the University of Applied Sciences in Seinäjoki, Finland.

To help navigation in the model, virtual mock-ups were fixed at the floor level, so flying was impossible. Also, viewers could not pass through

walls, so it was impossible to exit the virtual mock-up. As the use of a 3D mouse can be challenging for occasional users, a navigator was used in this study. An automated transition from one mock-up to another was used in some groups, and it caused dizziness in some participants.

## The Process of the Study

A project worker from the ICU organized the participants into groups of four to six people according to the working shifts of the nurses. The groups were multi-occupational, but there was at least one nurse in every group. The participants had not previously participated in designing hospital premises, and this was their first experience of VE. Participation was voluntary. In addition, information pertaining to videotaping, photographing, and recording the visits was provided, and consent was obtained from the participants.

The distribution of assignments in the project group was the following: (1) architect: presented the virtual rooms and answered technical and design questions, (2) navigator: guided the viewing of rooms and used the 3D mouse, (3) researcher: opened the conversation if needed, asked for details and grounds for changes, and defined comments, (4) nurse from ICU: answered functional questions, and (5) photographer: took videos and photos.

The visits in VE ran according to the design process plan in three iterative cycles. Each cycle had the same processes because there were always new participants in the groups. The participants received information in advance about the project, the location of the virtual laboratory, and the length and purpose of the visit. They were told that the design of rooms would be in three iterative cycles and modifications would be made after feedback. The participants were informed that the rooms were incomplete, and all comments and adjustments were more than welcome in order to motivate participants to express unusual proposals.

Before the design session, the researcher introduced the project group, demonstrated how the work in practice would happen in VE, and explained the outline of the VE presentation. The participants were told that they could interrupt and comment at any time during the presentation. All the visits to the VE were videotaped—first the rounds in virtual mock-ups and later the discussions after the rounds. The participants completed a questionnaire in which they could evaluate the details of the mock-ups and the experience of designing in a multi-occupational group.

The project group had planned the route for the VE presentation. The spaces were presented in the following order: the intensive care room and its bathroom, the nurses' station, and the intermediate care room and its bathroom. The architect presented the spaces with the same description to all the groups. The planned tour took approximately 15 min. The groups could then return to the virtual mock-ups they wished to evaluate in depth, and again the participants could interrupt and ask for details or comment at any point. The visit to the virtual rooms lasted 30–40 min.

After the presentation, the participants completed a questionnaire in which they could analyze the properties of the spaces more systematically and evaluate the virtual mock-ups and collaborative design experience. The aim of the questionnaire was to make sure that all comments and evaluations would be brought together. A lively exchange of views usually followed where, in addition to talk about the spaces, the discussions involved different functions, changes in functions, and the number of healthcare staff. On the whole, the visits lasted 1 hr. The design of the care rooms was completed in three iterative cycles. After each cycle, the modifications to the rooms were executed in accordance with the feedback.

## Participants

The total number of visitors to the VE was 238. There were altogether 47 multi-occupational groups in three iteration cycles. The nurses numbered 160 (67% of all the participants), making them the largest occupational group. The other participant groups were physicians, designers, cleaners, technicians, healthcare and facility managers, students, and individual healthcare workers, such as physiotherapists. The percentages of other participant groups vary from 0.5% to 7%. The visits to the VE took place in the spring of 2015. The timetable, the number of groups, and participants are shown in Table 1.

**Table 1.** The Timetable of the Project With Data on the Groups and Participants.

| Number of the Mock-Up | Time | Number of Groups | Number of All Participants | Number of Nurses |
|---|---|---|---|---|
| 1 | March 2015 | 14 | 61 | 41 |
| 2 | April 2015 | 18 | 89 | 62 |
| 3 | May 2015 | 15 | 88 | 57 |

None of the nurses had participated in the design of healthcare facilities previously. The nurses were quite experienced. The mean work experience was 16 ($SD = 10$) years, with 95% having work experience varying from 6 to 26 years. About 95% of the nurses had recorded their work experience in the questionnaire. There was some variation in the nurses' ages. The mean age of the nurses was 42 ($SD = 9$) years, and 95% of the nurses were between 33 and 51 years. Only 72% of the nurses stated their age in the questionnaire. Most of the nurses were women (88%), and this gender bias is typical in Finland nursing staff.

## Results

The results of the study are sorted according to two viewpoints. The first concerns the changes the nurses recommended in the new virtual mock-ups and the second concerns the nurses' satisfaction with the design method and tool. The results are thus divided into two parts. First, the comments and the requirements for changes from the virtual mock-ups are presented and then the statements from the questionnaire are analyzed.

### *The Development of Virtual Mock-Ups*

The first mock-up of the patient room was based on a summary of requirements compiled by the ICU staff. A single-patient room was the first requirement. The other requirements were good visibility, natural light and views of nature, good lighting and acoustics, ceiling lifts, adequate space around the bed, a private bathroom, and high levels of hand hygiene. In addition, it was recommended that the rooms be equipped identically. The requirements were based on EBD studies (Rashid, 2014; Redden & Evans, 2014; Thompson et al., 2012; Ulrich et al., 2008).

The first mock-up (Figure 1) of the patient rooms was almost unanimously opposed by all the participants. First, the absence of windows was discussed by all groups. In the beginning, when the need for windows and natural light was highlighted, the designer commented that it would be impossible to have natural light in all the rooms. Later, when it was repeated by all groups, the designer had to find an alternative spatial solution to provide more windows.

The second issue the nurses outlined during the first VE visit was the location of the bathroom. It is problematic when a patient using intensive care equipment is assisted to a bathroom; extra space around the bed is needed to move the patient. This problem was observed in the virtual mock-up. In the VE, it was easy to demonstrate to others how the nurses work with the patients and how much space is needed for it. Figure 2 shows the changed position of the bathroom in the second mock-up.

The third issue discussed was the size and the shape of the rooms, given all the equipment intensive care patients require. The need for space around the bed is extensive when the patient needs a ventilator, infusion pumps, monitors, and dialysis. In addition, the need for open floor space was highlighted. The nurses suggested which equipment could be placed on ceiling-mounted booms and which equipment could be placed on wheels.

The fourth point the nurses raised due to their work-related knowledge was visibility. It is crucial for the nurses to see the patients at all times and to receive assistance from other nurses. One practical example is the height of the dividing wall. The virtual mock-up enabled the nurses to see what is visible over the wall. Besides this, the groups discussed the factors regarding visibility. Patient safety was a reason for being able to see more over the wall, while patient privacy was an opposing consideration. In this study, the height

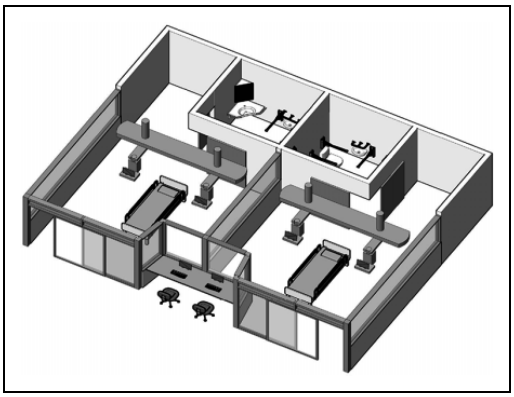

**Figure 1.** The first mock-up of the single-patient rooms in the intensive care unit.

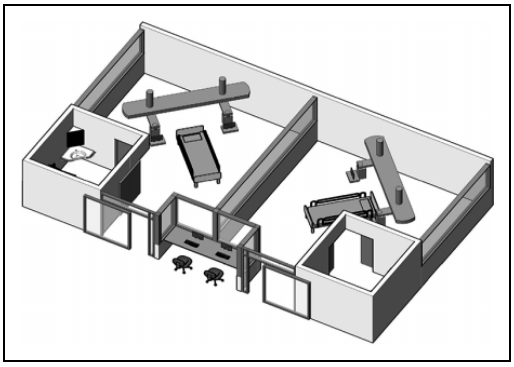

**Figure 2.** In the second mock-up, the position of the bathroom is changed.

of the wall was designed so that the nurses have good visibility into the other room, but the patients are not able to see each other. When privacy is needed, the glass parts of the wall can be made opaque in seconds.

The fifth point of evaluation was the furniture and accessories needed in patient rooms and bathrooms. The first and second mock-ups lacked most of the accessories. The nurses identified the need and suggested locations for them. In the third mock-up, the number and location of the accessories were corrected. Arguments for well-functioning accessories were also defined. In addition, being in the VE raises discussions on forthcoming changes, like the number of nurses, the availability of assistance, and changes in working culture. Figure 3 shows the third mock-up forwarded to the architectural designers. The changed location of the bathroom optimizes visibility, and the shape of the patient room is more functional.

## *Opinions on the Use of Walk-In VE*

Opinions on the use of co-design and walk-in VE were gathered by questionnaire, which was filled after each design session. The questionnaire was used to ensure all information was collected about the sessions. Those participants who did not talk actively could express their experiences in the questionnaire.

There were seven statements on the use of the walk-in VE and an open field for additional comments. The options to answer the statements were "fully agree," "partially agree," "don't know," "partially disagree," and "fully disagree." The statements were as follows: (1) Participation was useful, (2) The space was real and natural, (3) I felt like being inside the virtual rooms, (4) Active participation was easy, (5) Commenting was easy, (6) In discussions, my opinions were considered, and (7) Designing in a group is a useful method.

The results of the three iterate cycles can be seen in Table 2. Although the results are promising, there were additional comments on the usefulness of VE. Overall, nurses evaluated "The participation was useful" and "Designing in a group is a useful method" statements with high affirmative percentages. The positive responses to the statements "The space was real and natural" and "I felt like being inside the virtual rooms" increased in the third cycle. The statement "In discussions, my opinions were considered" received the lowest affirmative percentages, while the statements "Active participation was easy" and "Commenting was easy" also received low affirmative percentages. More analysis is needed to determine the reasons for these findings.

The nurses were satisfied with the process and the opportunity to participate in the design in a VE. The nurses (33%) who participated more than once considered the participation to be effortless, and they could focus more on evaluating the virtual mock-ups.

The nurses thought a limitation of the study was that only a few rooms were modeled. The

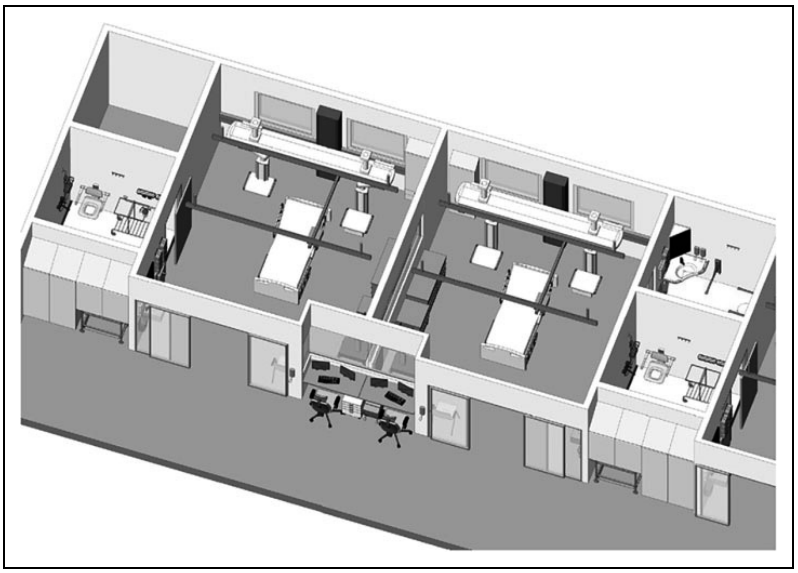

**Figure 3.** In the third mock-up, the bathroom has been moved to the side of the single-patient room.

**Table 2.** Results of the Questionnaire (in Percentages) Evaluating Co-Design and Virtual Mock-Ups.

| | First Visit ($N = 41$) | | | Second Visit ($N = 62$) | | | Third Visit ($N = 57$) | | |
|---|---|---|---|---|---|---|---|---|---|
| Statements | Totally Agree | Partly Agree | Rest | Totally Agree | Partly Agree | Rest | Totally Agree | Partly Agree | Rest |
| Participation was useful. | 78 | 15 | 7 | 63 | 29 | 8 | 77 | 21 | 2 |
| The space was real and natural. | 34 | 54 | 12 | 37 | 53 | 10 | 58 | 39 | 4 |
| I felt like being inside the virtual rooms. | 61 | 34 | 5 | 44 | 50 | 7 | 58 | 39 | 4 |
| Active participation was easy. | 42 | 49 | 10 | 32 | 53 | 15 | 42 | 47 | 11 |
| Commenting was easy. | 49 | 44 | 7 | 39 | 52 | 10 | 53 | 37 | 11 |
| In discussions, my opinions were considered. | 63 | 22 | 15 | 46 | 38 | 16 | 56 | 29 | 15 |
| Designing in a group is a good method. | 73 | 23 | 5 | 69 | 23 | 8 | 79 | 21 | 0 |

*Note*. Rest includes the answers "don't know," "partly disagree," and "totally disagree."

reason for choosing the patient room and bathroom was that these rooms are important, as their number will be high in the future ICU. The layout of the unit and the location of the auxiliary rooms—like the med room, storage, and central nurses' station—are also important to the nurses.

## Discussion

The findings in this action research study confirm the usability and usefulness of walk-in VE in collaborative design. The groups were multi-occupational, but the nurses—who were participating in a design process for the first time ever—were able to express their needs in the design of their future workplace.

*The findings in this action research study confirm the usability and usefulness of walk-in VE in collaborative design. The groups were multi-occupational, but the nurses—who were participating in a design process for the first time ever—were able to express their needs in the design of their future workplace.*

As this was one part of an action research project, it was not possible to conduct scientific testing, such as comparing different participation methods or modeling alternative participation groups. However, this was an actual design process in which the participants influenced their future working conditions, so their interest in participation was much stronger than if they had participated in a purely hypothetical study. The results of this study are important in particular since they were obtained in an actual design process. The results are very promising: They show co-design with virtual mock-ups is a functional solution.

A review of VR has emphasized that more attention should be paid to multidisciplinary collaboration (Kim et al., 2013). VR solutions provide practical tools for visual communication in many fields in architectural design. As users' perspectives are required frequently should practical VR solutions be adopted more often (Kim et al., 2013). There are several occupational stakeholder groups working in hospitals, and the design issues that affect their performance should be noted, but there are also key issues shared across multiple stakeholder groups (Lavender et al., 2015). Virtual mock-ups provide a useful tool to discuss design issues in multi-occupational groups. Although the comments of the nurses are highlighted in this study, the results of the collaboration involving the other participants were similar.

This study supports the previous studies on the usefulness of nurses' participation in design (Clark, 2014; Sundberg et al., 2017; Thompson et al., 2012). The nurses were satisfied with their role in the design, and the virtual mock-ups enabled the nurses to comment on their expertise and collaborate. Although the nurses did not have any previous experience of participating in the design of healthcare facilities, the co-design and virtual mock-ups supported their role and made them more equal in the design process. The designers also received valuable information on care processes and functional room solutions. Some statements like "In discussions, my opinions were considered," "Active participation was easy," and "Commenting was easy" received low affirmative percentages. The reasons for this could be the variation in the composition and size of the groups. If the group consisted of several nurses, the discussion was more vivid and the nurses got more support for their suggestions. There were in addition conversations about single-patient and multi-patient rooms. The change appears to be a major reorganization in clinical work. The transition to single-patient rooms has an impact on working culture, safety, and work processes. Visibility, audibility, and assistance were discussed in VE, as was how to prepare for these challenges in advance. These issues have been raised in several studies (Apple, 2014; Bonuel & Cesario, 2013; Lu et al., 2014; Redden & Evans, 2014; Sundberg et al., 2017).

Virtual mock-ups can be used in different phases of design, from a low fidelity sketch to a precise copy of the physical room. Increasingly, they can be used in simulation (Watkins et al., 2008; Wingler et al., 2020), and in the future, they can be used for familiarization with new facilities and occupancy. The study revealed that rooms designed with fewer details produced more discussion and more comments on missing items. The more detailed rooms were considered "complete" and were discussed less. The study demonstrates that nurses were able to observe missing items and place them in convenient positions relative to their work processes.

When this design process was conducted, there was only one VR technology available in which it was possible to present actual-sized virtual mock-ups; that technology was walk-in VE. Now there are new inexpensive VR solutions such as HMDs. However, their convenience in co-design is not evident, as by using them other participants' facial expressions and gestures are not visible. The use of alternative technical VR solutions in co-design needs further study.

Modeling in VR can provide bigger design layouts than separate rooms today, and modeling in VR has become easier and faster due to increased 3D modeling in architecture in general and the extensive use of game engines in modeling. Changes can be made quite quickly, even during the design session. Moreover, interactivity and augmented reality can be added. Movable VR solutions have become more common, which has increased use enormously.

## Conclusion

It is highly important to develop new methods and tools to enable nurses and other healthcare professionals to participate in design. Co-design with virtual mock-ups in walk-in VE is appropriate when designing new healthcare facilities and when the opinions of workers are important. In our study, the nurses were able to evaluate and improve virtual mock-ups and contribute to the design of the new ICU despite involving themselves for the first time in design. The visualization helped the nurses to understand the design and to express their work practices and practical requirements for space, furniture, equipment, and accessories. The nurses' comments helped the designer to understand spatial requirements and to remodel the spaces to support the nurses' working processes. A valuable exchange of views took place with different occupational groups concerning the spaces. Co-design with walk-in VE increases mutual understanding and respect in collaboration and democratizes teamwork in design. One limitation of the study was that only a few rooms were modeled. As VR tools provide larger layouts, they would be beneficial in future studies. The impact of end user participation is quite seldom evaluated in the quality of healthcare facilities. Post-occupancy evaluations should be performed more often to identify good design solutions, develop the design process, and prevent the repetition of undesirable design solutions. The concluding part of this action research study is to conduct a post-occupancy evaluation in order to study the impacts of collaborative design on user satisfaction.

Virtual mock-ups in walk-in VE can be used collaboratively, making it easier to receive feedback from multiple users at the same time. One third of the nurses were able to participate 2 or 3 times, and the nurses' familiarization with VR tools enabled them to concentrate more on design, evaluation, and detail. This aspect must be considered when arranging studies or focusing on the practical use of virtual mock-ups. More research on the use of co-design with virtual mock-ups is needed to strengthen its usability and provide practical applications for use in the design of healthcare facilities.

## Implications for Practice

- Healthcare professionals should be included in design teams to provide clinical expertise in design of healthcare facilities.
- Virtual environment, virtual mock-ups, and methods of collaborative design support participation in design, increase mutual understanding, and democratize teamwork.
- Virtual mock-ups helps healthcare professionals to understand better the design and to express their practices and requirements concerning spaces.
- Walk-in virtual environments can be used with multiple users at the same time to collect feedback of design simultaneously.

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# ARTICLE 5

**Staff participation in design with multiple tools: Impact on design and POE results**

Jouppila, T

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# Staff participation in design with multiple tools: Impact on design and POE results

**Tiina Jouppila, PhD candidate, MSc, RN**[1]

**Abstract**

**Objective:** This is a concluding part of an action research study to evaluate the impact on healthcare staff participation in the design of a new intensive care unit (ICU). Staff participated with multiple tools in the design; during the predesign phase utilizing co-design and virtual mock-ups, and also participating in the predesign evaluation (PDE) and postoccupancy evaluation (POE). Both the ICU design and evaluations were based on the principles of evidence-based design studies. **Method:** Staff satisfaction was evaluated with an online survey comprising 116 statements on 13 different topics used both in PDE and POE. There was space for open-ended comments after each topic. **Results:** There was a statistically significant difference (<.001) between PDE and POE results. There were considerable improvements in privacy, accessibility, safety and security, and acoustics. It was assumed that participation in the predesign phase would positively influence POE results, but there were no statistical differences in any topics. However, as a result of collaborative predesign phase, the staff was satisfied with these jointly designed patient rooms. Open-ended questions revealed the importance to continue functional and technical support for staff after commissioning and ensure that technical solutions are practical and well-functioning. **Conclusion:** The use of PDE and POE assists to set predetermined criteria and evaluate the success of design. Healthcare providers should see POE as a valuable part of design and commissioning process. Additionally, the use of POE should be made more effortless and the results more easily accessible to promote increased interest and usage.

**Keywords**

predesign evaluation, postoccupancy evaluation, end-user satisfaction, intensive care unit, evidence-based design

Participation in the design, construction, and evaluation of healthcare facilities provides a unique opportunity for learning by healthcare staff, and studies indicate that staff participation has an impact on improving functions and premises (Keys et al., 2017; Rechel et al., 2009). One issue preventing participation is the lack of design tools to enable staff to participate and contribute to design. Nurses and physicians are unable to read technical drawings or other documents, and they lack knowledge of design and construction processes (Keys et al., 2017; Reno et al., 2014). To support participation, multiple media of collaboration and visualization have taken

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advantage of physical and virtual mock-ups (Jouppila & Tiainen, 2021; Lavender et al., 2020; Redden & Evans, 2014; Wingler et al., 2020; Wingler et al., 2019).

Evidence-based design (EBD) providing research knowledge and best practices has expanded as an important source of information in the design of healthcare facilities, and healthcare staff need some knowledge of EBD when participating in the design process (Anåker et al., 2017; Cesario, 2009; Redden & Evans, 2014; Sundberg et al., 2017; Ulrich et al., 2008). The chief perspective has been that of the patient's well-being and healing (Codinhoto et al., 2008; Rechel et al., 2009), but increasingly staff well-being, performance, and recruitment are steering the design of new facilities (Rechel et al., 2009; Steinke et al., 2010). Participation should start from the initial design stage (Rechel et al., 2009), and participants should represent the different healthcare occupations because they all have different needs for space when working (Lavender et al., 2015; Lavender et al., 2020; Rechel et al., 2009; Redden & Evans, 2014). The participation of nurses is important as they are usually the biggest occupational group in hospitals, and due to their direct daily activities with patients, the layout of the facility affects their workflows and processes (Clark, 2014; Redden & Evans, 2014; Sundberg et al., 2017). Furthermore, the design of a hospital has an impact on nurses and their job satisfaction and stress (Berry & Parish, 2008; Rechel et al., 2009).

While participation in design is rare among healthcare staff, participation in systematic evaluation of facilities and functions after occupation is even rarer. Postoccupancy evaluation (POE) was launched in the 1960s, but POEs are often conducted as a singular research study rather than as part of larger commitment to continuous quality improvement throughout the design and construction process (Elf et al., 2016; Göçer et al., 2015). There are a few countries where POE research and practice have been more actively used (Brambilla & Capolongo, 2019; Li et al., 2018). More and more studies are linking EBD and POE together, assuring that the latest results for EBD studies and practice are used in design (Brambilla & Capolongo, 2019; Steinke et al., 2010).

Very few studies are conducted in a manner that enables the healthcare staff to participate in both the design and the predesign evaluation (PDE) and POE of the facilities. In this action research study, healthcare staff took part in the design and PDE and POE of the actual design and construction process of an intensive care unit (ICU) in Seinäjoki, Finland. The impact was studied by comparing the results of the PDE and POE, comparing the results of the POE against the participation in the predesign phase, and analyzing the open-ended comments of POE. The research question is: What impact staff participation in the design of the new ICU has on the results of the POE? The staff participated in the PDE in spring 2014 before the design process started. Codesign was used as a method and virtual mock-ups as a tool in the predesign phase of the new unit in 2015. The staff participated in multioccupational groups (four to six members) in the design of a single patient room, a private bathroom, and the nurse charting station in a natural-sized, using walk-in virtual environment (CAVE). Additionally, the staff were represented in the construction project group during the design, construction, and commissioning. The new ICU with 24 single patient rooms was commissioned in spring 2018 and the POE was conducted in autumn 2019. The same questionnaire was used in both the PDE and POE. The questionnaire comprises 13 different topics including 116 statements altogether. After each topic, there is space for open-ended comments.

## POE of Healthcare Facilities

POE is defined as "the systematic evaluation of health service buildings or facilities assumed to occur sometime after their occupation and usually defined period of use such as 12 months up to 2 years" (Carthey, 2006, p. 58). POE has been poorly utilized in the evaluation of healthcare facilities, though there have been research studies contributing to the available results. The number of studies and reviews indicates a growing interest in the topic (Brambilla & Capolongo, 2019; Göçer et al., 2015; Li et al., 2018). There are considerable variation in how POEs are conducted in different countries (Brambilla &

Capolongo, 2019; Li et al., 2018). According to recent reviews (Brambilla & Capolongo, 2019; Li et al., 2018), there were almost 20 POE protocols and numerous other case-related tools and methods with diverse purposes of use. Using Ulrich's EBD framework and 13 POE instruments, Brambilla and Capolongo (2019) analyzed how to test health, sustainability, or both health and sustainability. POE methods include subjective methods—like occupant surveys, interviews, walkthroughs, and focus groups—and physical measurements—like energy, electricity, water and indoor environmental quality (thermal conditions, lighting, indoor air quality, and acoustics), and audits (Göçer et al., 2015; Li et al., 2018). The most frequently used method is a survey to evaluate end user satisfaction.

When evaluating healthcare facilities, the focus has shifted more onto EBD variables and outcomes (Brambilla & Capolongo, 2019). Earlier studies emphasized patient health and well-being (Codinhoto et al., 2008), while the health and performance of staff and sustainability have additionally been investigated recently (Brambilla & Capolongo, 2019). The scope of POE studies and protocols is comprehensive, and a great variety of variables is examined (see Table 1, where examples of POE studies are assessed according to facility, participants, method, and variables). The role of stakeholders in the design and building process has increased, especially in the healthcare field, and stakeholders' expectations and needs vary. When including POE in the design and building process, it is possible to bridge the gap between design intent and the actual performance of the building with better information and knowledge (Göçer et al., 2015; Elijah-Barnwell and Friedow, 2014).

When evaluating healthcare facilities, it is useful to set targets to help measure the success of the design (Pati & Pati, 2013; Schreuder et al., 2015). Elf et al. (2016) have criticized POEs that focus more on the experiences and opinions of users rather than on predetermined quality criteria. It is recommended that commitments are made to PDE and POE (Alvaro et al., 2016; Guinther et al., 2014; Kotzer et al., 2011). POEs have been conducted as research instead of part of a design and construction process to ensure continuous improvement (Elf et al., 2016). While the use of POEs has increased, there are a number of barriers that prevent POEs from being an essential part of design and construction practice (Guinther et al., 2014). Barriers include issues like the cost and time needed for POEs, a lack of research expertise, and an unwillingness to expose problems and failures (Guinther et al., 2014). Healthcare professionals should have knowledge to request a POE, and, as the methods and variables are numerous, it is difficult to know which method to use to achieve the goals. Li et al. (2018) have summarized the current condition of POE research and propose five transitions that POE efforts should pursue (1) from one-off to continuing, (2) from high-level to detailed, (3) from researcher-oriented to owner/occupant-oriented, (4) from academia to industry, and (5) from independent to integrated. Current situation in many healthcare organizations requires more familiarization with POE, cases of confirmative outcomes to design quality, and change in construction practice to reach those transitions.

*Healthcare professionals should have knowledge to request a POE, and, as the methods and variables are numerous, it is difficult to know which method to use to achieve the goals.*

## The Methods of the Action Research Study

This action research study presents the use of multiple tools in the design of the new ICU to support end-user participation. The basis for the design of the new ICU was formed from the principles of EBD studies. The management of the ICU was familiarized with EBD in 2012 and it was decided to utilize this knowledge in the design of the new facilities with a goal to build the first ICU in Finland based on single patient room concept. The clinical planning for the design was done by gathering the requirements for the ICU to support the healing and well-being of patients and the well-being and performance of staff. The EBD requirements were compiled from studies and recommendations

**Table 1.** Postoccupancy Evaluations of Different Healthcare Facilities.

| Authors | Facility | Participants | Method | Variables |
|---|---|---|---|---|
| Kotzer et al. (2011) | Children's hospital | Staff (38% + 49%) families (60 + 67) | Pre- and postoccupancy evaluation<br>Survey | Satisfaction related to light, noise, temperature, esthetics, amenities, safety, security, and privacy |
| Guinther et al. (2014) | Emergency department | Staff, visitors, and patients | Postoccupancy evaluation Phase 1—200 h observation Phase 2—surveys (315) and eight focus groups | Privacy<br>Confidentiality |
| Ferri et al. (2015) | Intensive care unit | End-users (24 + 15) healthcare providers, support staff, and patient family members | Pre- and postoccupancy evaluation interview | Atmosphere<br>Physical spaces<br>Family participation in care<br>Equipment |
| Schreuder et al. (2015) | Medical center nonpatient-related | Staff (729 + 664) | Pre- and poststudy with control group<br>Online survey | Safe<br>Pleasant<br>Sustainable |
| Alvaro et al. (2016) | Continuing care and rehabilitation facility | Staff (267 + 379) and patients (158 + 175) | Pretest–posttest quasi experiment<br>Quantitative survey<br>Comparison hospital | Connection to community, the city, and nature<br>Opportunities for social interaction<br>Inspiring activity |
| Alzimer et al. (2019) | Academic Medical Center (AMC) bed tower three patient rooms | 8 Auditors (23 surveys; architect, four facility workers, clinician, student, and engineer) | Postoccupancy evaluation<br>Center for Health Design (CHD) checklist evaluation tool | Patient safety<br>Worker safety and effectiveness<br>Quality of care and patient experience<br>Organizational performance |

**Figure 1.** Two-dimensional photograph of virtual mock-up presenting designed single patient in intensive care unit.

(Rashid, 2014; Redden & Evans, 2014; Thompson et al., 2012; Ulrich et al., 2008). The requirements were single patient rooms, optimal visibility, natural light and windows, privacy, effective lighting, pleasant acoustics, patient lifts, adequate space around the bed, the implementation of required hand hygiene, standardized patient rooms, and the grouping of patient rooms. These requirements were included in the clinical planning, and they were forwarded to the design brief.

The PDE was conducted in April 2014, and it revealed issues that should be taken account in design of the new facilities. The topics that needed the most improvement were privacy, lighting, indoor air, and acoustics. The survey used in the PDE was a POE questionnaire developed in a former design project for a hospital extension in Seinäjoki, Finland, in 2010. It was used earlier in this former hospital extension project (including 20 different units) and in other ward renovation projects and new hospital buildings in three different hospitals mostly as POEs after commissioning. The statements of the questionnaire were grounded in EBD studies and literature, comparison of other POE protocols, and summary of topics discussed in virtual design sessions in this former hospital extension project. The topics and statements were compiled and modified suitable for Finland culture with a project group (architect, nurse, and researcher).

The staff participated in the design of the new facilities with the designers during the predesign phase in spring 2015 utilizing codesign and virtual mock-ups (Figure 1). The design of the single patient rooms, private bathrooms, and nurse charting stations was executed in a natural size walk-in virtual environment (CAVE) using multi-occupational groups (47 groups). CAVE is a room with three glass walls, a ceiling, and a floor. The size of CAVE was 9 $m^2$ (97 sq. ft.). Images were projected onto these glass surfaces, and

when viewed with stereoscopic glasses, they transformed into a 3D full-scale environment (Tiainen & Jouppila, 2019). The design of the virtual mock-ups was iterative and comprised three separate rounds. After each round, the virtual mock-ups were redesigned after feedback gathered from the participants. The results of this design process were adopted into the architectural design. There were altogether 238 participants from many different occupational groups. The largest occupational group was nurses (67%). The other participant groups were physicians (7%), designers (6%), cleaners (6%), technicians (6%), healthcare and facility managers (3%), students (1%), and other individual healthcare workers (altogether 4%). The feedback of this study was gathered with a questionnaire of visit and all these 47 group visits were video-recorded. The participants' general feeling was that participation in codesign with virtual mock-ups was useful and designing in groups was a useful method (Tiainen & Jouppila, 2019). As the nurses were the largest occupational group, their satisfaction was studied separately. The nurses were satisfied with their role in the design process, they could specify their requirements in walk-in virtual environment, and their suggestions were incorporated into the architectural design (Jouppila & Tiainen, 2021). The participants expressed demand for design of larger layout to evaluate proximities and how rooms are related to each other (Tiainen & Jouppila, 2019). During the architectural design phase and the construction, the ICU had several members in the construction project team.

The old ICU had seven beds and four intermediate care beds for neurological patients. The beds were in three rooms parallel on one side and all other rooms—included the bathroom, supply rooms, utility room, office, and med room—were on the opposite side of patient beds. The ICU beds were in two rooms and they were separated by curtains. The old ICU was built in 1978 and there had been only minor renovations over the years. As care in ICUs has grown more technical and technological, the space for beds with all the equipment was running short and the air-conditioning was unsatisfactory. The area of the old ICU was 980 $m^2$ (10,549 sq. ft.). The number of staff was 77 including the consulting physicians.

During the architectural design, it was decided to combine all intensive and intermediate care into one unit with 24 single patient rooms, including two isolation rooms. The rooms are divided into four modules with six single rooms each. There are six intensive care single rooms, six single rooms for trauma and surgical patients, six single rooms for neurological patients, and six single rooms for cardiac patients. The area of the intensive care patient room is 25 $m^2$ (269 sq. ft.) and the area of the intermediate care patient room is 20 $m^2$ (215 sq. ft.) adjoined by a separate 5 $m^2$ (54 sq. ft.) accessible private bathroom. All the modules include a decentralized nursing station, supply rooms, utility rooms, and med rooms, and the modules have a common staff coffee room. The new ICU was renovated in the middle of the hospital in an old surgical ward (Figure 2). The new ICU has two enlargements on both sides of the ward and the area of the new unit is 2,400 $m^2$ (25,833 sq. ft.) and some rooms—like offices, one supply room, the meeting room, and staff break room—were placed on a lower floor. The number of staff in the new unit was 117 excluding consulting physicians.

The new intensive and intermediate care unit was commissioned in April 2018. The POE was conducted after 18 months' occupancy to evaluate and compare the results of the PDE and POE, realization of the requirements for space, and the impact of staff participation on design. The time line of the study is presented in Table 2.

Very few studies are conducted in a manner that enables the healthcare staff to participate in both the design and the PDE and POE of the facilities. In this action research study, healthcare workers took part in the design and PDE and POE of the actual design and construction process of an ICU in Seinäjoki, Finland. The impact is studied by comparing the results of the PDE and POE, comparing the results of the POE against the participation in the predesign phase, and analyzing the open-ended comments of POE. The PDE and POE were conducted as an online survey. Invitations and reminders to participate were sent by email to the staff. The questionnaire consists of 116 statements on 13 different topics: yards and entrances, architecture, acoustics, lighting, durability, safety and security, functionality, indoor

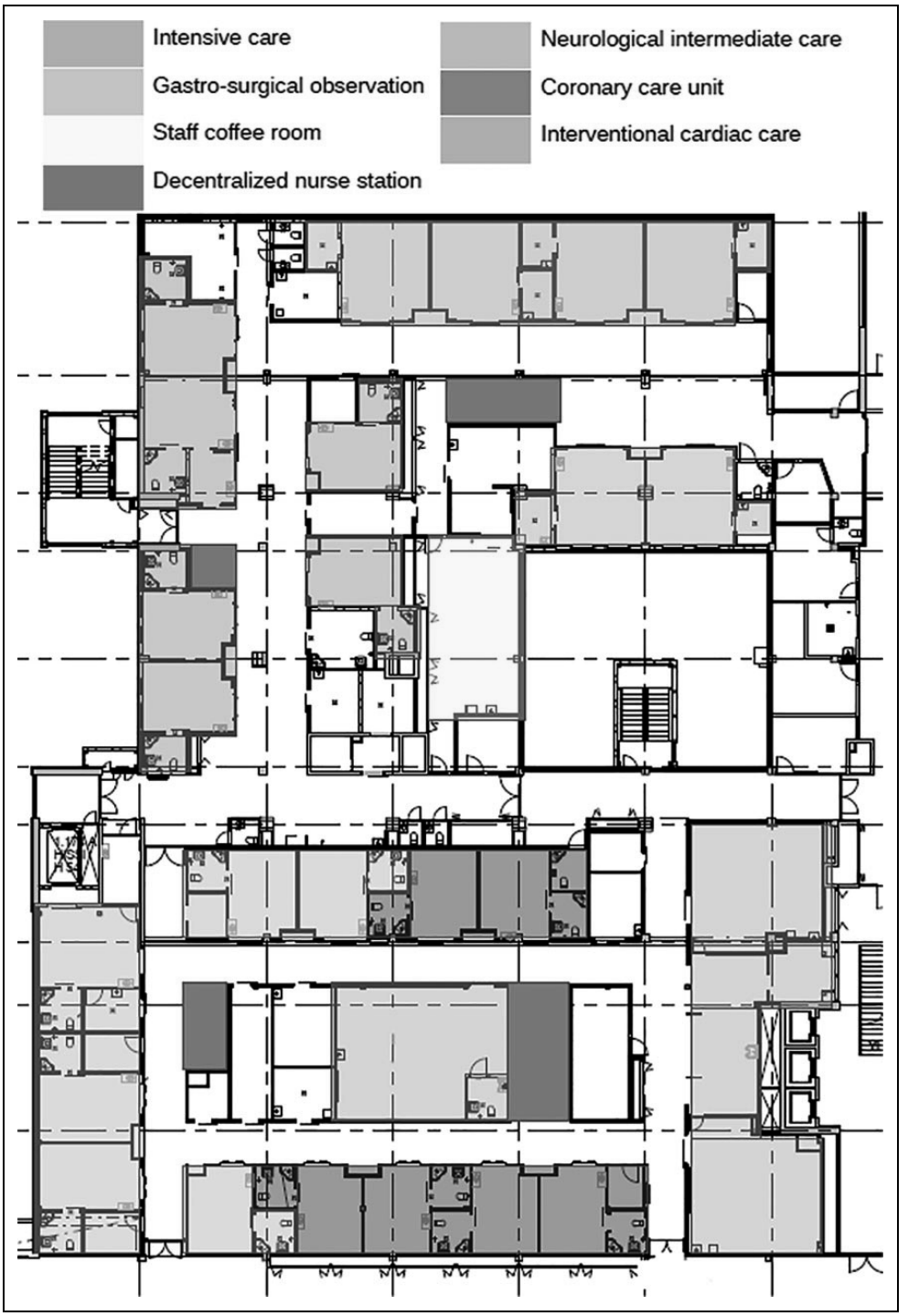


**Figure 2.** The layout of the new intensive care unit.

**Table 2.** The Phases of User Participation With Number of Participants and Occupation.

| Year | The Phase | The Number of Participants | The Occupation of Participants |
|---|---|---|---|
| 2012 | Introduction to evidence-based design | | |
| 2012–2013 | Clinical plan for design | | |
| 2014 | Predesign evaluation | 38 Participants (of 77 staff members) | Nurses 63%, physicians 18%, unit officers 11%, and practical nurses 8% |
| 2015 | Codesign with virtual mock-ups | 238 Participants, 47 groups in three iterative rounds | Nurses 67%, physicians 7%, the rest (26%) were designers, cleaners, technicians, health and facility managers, students, and other healthcare professionals |
| 2015–2016 | Architectural design | | |
| 2016–2018 | Construction | | |
| 2018 | Intensive care unit operational from April 2018 | | |
| 2019 | Postoccupancy evaluation October 2019 | 56 Participants (of 117 staff members) | Nurses 80%, unit officers 5%, clinical secretaries 5%, practical nurses 5%, physicians 2.5%, and cleaners 2.5% |

air, privacy, social interaction, comfort and aesthetics, accessibility, and usability. There is a different number of statements for each topic (Table 3). After each topic, there is space for open-ended comments. The questionnaire also includes demographic data and questions about the number and quality of statements and the relevance of gathering feedback. The same questionnaire was utilized in both evaluations to compare and evaluate the differences in staff satisfaction between the old and new ICU facilities. The response alternatives are *fully agree* (=4), *mostly agree* (=3), *mostly disagree* (=2), *totally disagree* (=1), and *does not concern me* (=0).

The surveys were conducted with the Webropol survey tool. Data were analyzed using SPSS Version 26 Software. The means of responses of statements for each topic were summarized and the PDE and POE results compared, and the effects of participation in the design were compared in groups contrasting the results of those who had participated in the predesign with those who had not. The independent *t* tests were conducted to evaluate differences in means.

Participation in the PDE and POE was voluntary, and no ethical approval was required because the participants were staff members. These evaluations were part of an extensive design research and construction project, and permission to conduct this research was granted by the hospital district.

## Results

The results are divided into four sections: (1) the demographic results, (2) the comparison of the PDE and POE, (3) the impact of participation in the predesign phase and, (4) the open-ended comments of POE.

### *Demographic Data*

The PDE survey was sent by email to ICU staff (77 members). The response rate was 49% (38 participants). The largest occupational group was nurses (63%). The other occupational groups were physicians (18%), unit officers (11%), and practical nurses (8%). The POE survey was sent by email to the staff of the new intensive and intermediate care unit (117 members). The response rate was 48% (56 participants). The participants were nurses (80%), unit officers (5%), physicians (2.5%), clinical secretaries (5%), practical nurses (5%), and housekeepers (2.5%). Work experience varied in the POE from 1 year to over 30 years,

**Table 3.** The Topics of the Survey With the Number of Statements and Examples of Statements.

| Topics | Number of Statements | Example of Statements |
|---|---|---|
| Yards and entrances | 8 | There is adequate parking for patients, visitors, and staff, including disabled people |
| Architecture | 9 | The layout of the building is logical and supports finding one's way |
| Acoustics | 8 | The air-conditioning doesn't cause a disturbing noise |
| Lighting | 6 | The toilet and bathroom facilities, with the automatic control of lighting, are a suitable solution |
| Durability | 7 | The interior flooring materials are durable and easy to maintain |
| Functionality | 6 | Operational objectives are realized in the new premises |
| Indoor air | 8 | Patients and staff can easily adjust the temperature in patient rooms and offices |
| Safety and security | 19 | There are good possibilities to isolate patients |
| Privacy | 7 | The patient can have a private conversation with staff or loved ones |
| Social interaction | 7 | A loved one can spend the night, if necessary, in the patient's room or elsewhere on the hospital premises |
| Comfort (patient and staff) | 17 | The premises have varying views, colors, and surface materials |
| Accessibility | 8 | The toilet and bathroom facilities can be used independently or with assistance |
| Usability | 6 | The customers'/patients' and staff's walking distances are minimized |

with 32% having worked for 1–9 years, 24% for 10–19 years, 20% for 20–29 years, and 24% for over 30 years. Most of the participants were women (84%). The nurses were the largest occupational group in both evaluations.

## Results Comparing PDE and POE

When comparing the means of topics, the means for the POE were higher, and there were statistically significant differences between these two evaluations (Table 4). The desired mean for POE topics was 2.5, that is, half of respondents fully agree or mostly agree. All topics except social interaction achieved the desired mean. The highest means were in privacy, accessibility, safety and security, and acoustics. The lowest means were in comfort, yards and entrances, functionality, and social interaction.

When evaluating the statements more carefully according to the different topics, some statements either decreased or increased the means in the POE (Table 5). In privacy, the lowest mean came from the statement "the view from the patient room is beautiful and there are attractive items to look at." In lighting, the lowest mean was for the statement "there is natural light in all patient and examination rooms." Indoor air was evaluated as good, but the possibility to open a window or door to the outdoors was evaluated to be poor. In acoustics, the lowest mean was for the statement "Sound insulation in the open nurse stations is good." Durability was the most demanding part to evaluate. In the statements, replies of "does not concern me" ranged from 18% to 40%. Also some individual statements had a high number of "does not concern me" replies, like "cleaning the facilities is easy" and "the acoustic environment is suitable for hearing impaired persons and hearing aid users." Among the single statements, only the possibility for overnight stay by family members was estimated to be lower in the POE than in the PDE albeit single patient rooms.

## Requirements for the New ICU

Issues to be improved in the design of the new ICU were revealed in the PDE. The issues that

**Table 4.** Comparison of PDE and POE.

| Topics | *N* (PDE 2014) | Mean | *SD* | *N* (POE 2019) | Mean | *SD* | *p* Value |
|---|---|---|---|---|---|---|---|
| Privacy | 38 | 1.44 | .41 | 54 | 3.46 | .37 | <.001 |
| Accessibility | 36 | 1.99 | .54 | 55 | 3.14 | .46 | <.001 |
| Safety and security | 38 | 2.16 | .45 | 55 | 3.08 | .47 | <.001 |
| Acoustics | 37 | 1.45 | .48 | 55 | 3.04 | .63 | <.001 |
| Durability | 35 | 1.92 | .68 | 48 | 2.99 | .62 | <.001 |
| Lighting | 38 | 1.53 | .57 | 55 | 2.89 | .50 | <.001 |
| Architecture | 38 | 1.82 | .55 | 55 | 2.87 | .41 | <.001 |
| Indoor air | 37 | 1.41 | .49 | 55 | 2.85 | .55 | <.001 |
| Usability | 37 | 1.73 | .58 | 55 | 2.75 | .49 | <.001 |
| Comfort | 36 | 1.81 | .48 | 55 | 2.72 | .44 | <.001 |
| Yards and entrances | 35 | 2.21 | .54 | 55 | 2.63 | .52 | <.001 |
| Functionality | 37 | 1.39 | .47 | 55 | 2.53 | .52 | <.001 |
| Social interaction | 37 | 1.43 | .41 | 54 | 1.94 | .61 | <.001 |
| Total | 38 | 1.76 | .41 | 55 | 2.86 | .35 | <.001 |

*Note.* Results organized by order of POE means.

**Table 5.** Lowest and Highest Means of Statements in Different Topics (POE).

| Topic | Highest Mean | Lowest Mean |
|---|---|---|
| Yards and entrances | Entrances are obvious and logically positioned (3.1) | Sheltered outdoor areas are easily accessible by patients, visitors, and staff (2.2) |
| Architecture | Building relates well to other surrounding buildings (3.2) | All buildings have their individual character (2.6) |
| Acoustics | Sound insulation in patient rooms is good (3.3) | Sound insulation in the open nurse stations is good (2.6) |
| Lighting | Patients and staff can block out disturbing sunlight with curtains or blinds (3.4) | There is daylight in all patient rooms (1.4) |
| Durability | Wall materials are durable (3.3) | Roof materials are durable (2.7) |
| Functionality | Planned care models are realized (3.0) | Good layout save steps (2.0) |
| Indoor conditions | Windows do not cause any draft (3.4) | It is possible to open doors or windows to the outdoors (1.5) |
| Safety and security | Isolation possibilities are good (3.7) | The layout is safe and controllable (2.6) |
| Privacy | Patients can have privacy (3.8) | There are beautiful items or views to look at in rooms (2.4) |
| Social interaction | Spaces support sociality with family members (2.6) | Patients can make snacks and drinks on the ward (1.3) |
| Comfort | Facilities are clean and well maintained (3.5) | The view outside is pleasant (1.8) |
| Accessibility | Bathrooms are accessible and safe (3.4) | Outdoor and indoor signage ensures accessibility to all (2.8) |
| Usability | Important objects have a reserve power system (3.3) | Walking distances are minimized (2.2) |

needed the most improvement were privacy, lighting, indoor air, and acoustics. Significant improvement occurred in all of these areas. Requirements based on EBD were also set for the design. All the patient rooms were constructed as single patient rooms, and this ensures privacy. Optimal visibility was realized with windows between patient rooms and corridors. The sliding doors also had windows. The demand for natural light and windows was partly realized. Thirteen of the 24 patient rooms had windows. Pleasant acoustics were also realized and checked with

**Table 6.** Comparison of Groups "Participated in Design" Versus "Did Not Participate in Design."

| Topics | *N* (Participated) | Mean | *SD* | *N* (Not Participated) | Mean | *SD* | *p* Value |
|---|---|---|---|---|---|---|---|
| Privacy | 21 | 3.54 | .34 | 33 | 3.41 | .38 | .236 |
| Acoustics | 21 | 3.21 | .53 | 34 | 2.93 | .67 | .099 |
| Safety and security | 21 | 3.17 | .47 | 34 | 3.03 | .47 | .289 |
| Accessibility | 21 | 3.16 | .45 | 34 | 3.12 | .47 | .754 |
| Durability | 21 | 3.06 | .61 | 27 | 2.94 | .64 | .498 |
| Lighting | 21 | 2.98 | .47 | 34 | 2.83 | .51 | .295 |
| Indoor air | 21 | 2.95 | .50 | 34 | 2.78 | .58 | .270 |
| Architecture | 21 | 2.94 | .46 | 34 | 2.83 | .37 | .314 |
| Comfort | 21 | 2.85 | .34 | 34 | 2.65 | .49 | .106 |
| Usability | 21 | 2.71 | .49 | 34 | 2.78 | .50 | .601 |
| Yards and entrances | 21 | 2.65 | .46 | 34 | 2.63 | .55 | .902 |
| Functionality | 21 | 2.53 | .54 | 34 | 2.53 | .52 | .978 |
| Social interaction | 21 | 1.86 | .46 | 33 | 1.98 | .70 | .480 |
| Total | 21 | 2.93 | .33 | 34 | 2.81 | .37 | .222 |

*Note.* The results are organized by order of the group "participated in design."

acoustics measurement. In the patient rooms, patient lifts, adequate space around the bed, and the implementation of required hand hygiene were realized. The standardized patient rooms were grouped into four six-single room modules.

## *Results Comparing Participation in Design*

Staff participated in the design of the single patient room, private bathroom, and nurse charting station utilizing codesign and virtual mockups. The reason for choosing these spaces was the number of these rooms and the forthcoming change in nursing procedures due to the single patient rooms. The assumption was that those who participated in the predesign phase would be more satisfied with the new facilities than those who did not participate. This assumption was discovered to be incorrect (Table 6). There were no statistically significant differences between those who participated in the design and those who did not. The participants were satisfied and dissatisfied with the same topics. As result of collaborative predesign phase, the staff was satisfied with these jointly designed rooms.

## *Open-Ended Comments*

The number of open-ended comments (178) was higher in the POE than in the PDE (92), and the open-ended comments could be categorized into four classes: space, technology, function, and safety. Many comments were categorized into several classes, like long distances, which affect space, function, and safety issues. The open-ended comments revealed issues to be considered more closely. The biggest concern was the lack of windows in some patient rooms. There were also difficulties in using the automated lighting system due to the settings, presence control, and insufficient knowledge about its use. The air conditioning caused a draft and was noisy at night. The size of the new unit, corridors, and the layout resulted in long walking distances for staff and family members. The size of the new unit had an effect on feeling of safety, loneliness, and assistance. There were also comments on the two-floor layout. Although the spaces needed for patient care are located on the same floor, the new unit's two-floor design is uncomfortable and causes inconvenience for the staff. The siting of the break room, meeting room, and unit leaders' offices on the lower floor proved to be impractical. The two-floor solution was determined during the architectural design phase. The number of single patient rooms was deemed essential, and there were no opportunities to enlarge the floor area; hence, the nonpatient spaces were relocated downstairs. Furthermore, some spaces were deemed to be too small or too few in number,

such as some intermediate care rooms, which are narrow due to technical issues, and the lack or size of supply rooms.

The respondents considered the feedback collection to be important and they valued both the PDE and POE. Ninety-six percent of respondents in both surveys thought the gathering of feedback from staff was important. They expected improvements in the exposed shortcomings. In general, the respondents thought that the number of statements was too high and some statements or topics were difficult to comment on, like yards and entrances and durability.

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## Discussion

Comparing the PDE and POE results, there was a significant improvement in most of the topics. The biggest improvements in means were in privacy, accessibility, acoustics, lighting, and indoor air. There was dissatisfaction due to a lack of windows in some of the patient rooms. The deep plan and enlargements prohibited the certain placement of windows, and the shortcoming of the windows were compensated for with dynamic lighting that follows a circadian rhythm. Furthermore, there are settings for good working lighting and nature wallpaper. Natural light is provided also from skylights in the corridors.

Social interaction had the lowest means in both evaluations. As the survey is the same for all patient wards, in the ICU, common spaces with amenities for the patients were not designed. The participants were satisfied with the single patient rooms in terms of sociality with family members.

The EBD requirements for design were fulfilled, and the shortcomings found in the PDE were improved upon in the new unit. EBD supported the staff in the design process and assisted them in justifying their requirements. The change to single patient rooms, the merging of all intensive and intermediate care, new technology, and the orientation of new employees require the updating of work procedures, and more time is needed to promote safety, teamwork, and staffing, as noticed in other studies, too (Ferri et al., 2015; Vifladt et al., 2016).

There were no statistical differences between those who participated in the predesign phase and those who had not participated concerning any topic. The participants were satisfied and dissatisfied with the same topics. If the scale had been broader, some differences in means might have been found. Spaces that were designed collaboratively—the single patient room, private bathroom, and nurse charting station—and the advances they brought were generally accepted, and there were only minor comments on these rooms (Jouppila & Tiainen, 2021). During the predesign process, valuable observations and empirical information were assembled for the design of the whole ICU, including proximities, necessary spaces, visibility, and access to assistance. If, in the predesign phase, the target of the design had been to provide a larger layout rather than single mock-up rooms, it might have given the staff a broader understanding of the new ICU. The visualization of a larger layout would have been helpful for staff when investigating proximities and simulating care processes. The transition from single mock-ups to larger layouts is possible now with virtual reality tools.

*The visualization of a larger layout would have been helpful for staff when investigating proximities and simulating care processes. The transition from single mock-ups to larger layouts is possible now with virtual reality tools.*

The open-ended comments included more specific feedback on spaces, technology, functions, and safety. The larger layout makes the nurses feel unable to control the whole unit, even though the doors are closed and there are technological aids,

such as an entrance intercom, electronic patient record system, and patient alarm system. Additionally, the decentralized nursing stations appear to add to walking distances and reduce opportunities for support and consultation. The decentralized nursing stations have many advantages and disadvantages, and the nursing culture is undergoing change (Fay et al., 2017; Real et al., 2017).

The POE revealed the importance of information and instructions on use of technical systems (Schreuder et al., 2015). There were inconsistencies with lighting settings and presence control, causing problems during the night. These defects of the lighting system were corrected. Additionally, dynamic lighting was not fully in use due to the inadequate introduction of its benefits and significance.

## Conclusion

Participation in the design, construction, and evaluation of healthcare facilities provides a unique opportunity for learning by healthcare staff, and studies indicate that staff participation has an impact on improved quality. However, there has been a lack of design tools to enable staff to participate and contribute to the design. While participation in design is rare among healthcare staff, even rarer is participation in the systematic evaluation after occupation. The participation increases the expertise of staff to evaluate design and outcomes. Interesting field for study would be to provide pretraining for staff in design and assess the influence on outcomes.

The transition to single patient rooms reveals many advantages in the evaluated topics, such as privacy, acoustics, safety and security, and accessibility. However, the changes in working processes, decentralized nursing stations, longer distances, and the merging of all intensive care caused a deterioration in sense of security and an experience of decreased social support. In similar cases, the change has meant that it has taken many years to recover the sense of security (Ferri et al., 2015; Vifladt et al., 2016). Based on the open-ended questions, it is important to continue to provide functional and technical support to staff and ensure that technical solutions are practical and well-functioning.

The PDE and POE questionnaires included too many statements, and some of them were difficult to assess, such as durability. The participants additionally suggested a reduction of statements in the survey not relevant to ICUs. The open-ended comments provided valuable information on the number and quality of the statements. Furthermore, number and quality of the comments in POE revealed the increase in staff competence to evaluate the design. The respondents regarded feedback collection as important and valued both the preevaluation and POE. Ninety-six percent of the respondents in both surveys considered gathering feedback from the staff to be important. The limitations of this action study are relatively small number of participants in evaluations, though the percentage in both evaluations is situated near 50%. The other limitation is that the questionnaire is not validated. The POE questionnaire used in this study has been utilized over 10 times in different building projects providing at present adequate data for modification and validation.

The significance of the study lies in the longitudinal action research study and large data of the whole design, construction, and evaluation of participation in the design and the transition to the single patient room. The use of PDE and POE assists to set predetermined criteria and evaluate the success of design. Healthcare providers should see POE as a valuable part of design and commissioning process. Additionally, the use of POE should be made more effortless and the results more easily accessible to promote interest and usage.

*The significance of the study lies in the longitudinal action research study and large data of the whole design, construction, and evaluation of participation in the design and the transition to the single patient room.*

## Implications for Practice

- Healthcare professionals should have knowledge to request a POE and competence to set targets for design of new healthcare facilities.
- The respondents considered the feedback collection to be important and they valued both the PDE and POE.
- It is important to continue to provide functional and technical support to staff after commissioning and ensure that technical solutions are practical and well-functioning.
- The use of POE should be made more effortless and the results more easily accessible to promote increased interest and usage.

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