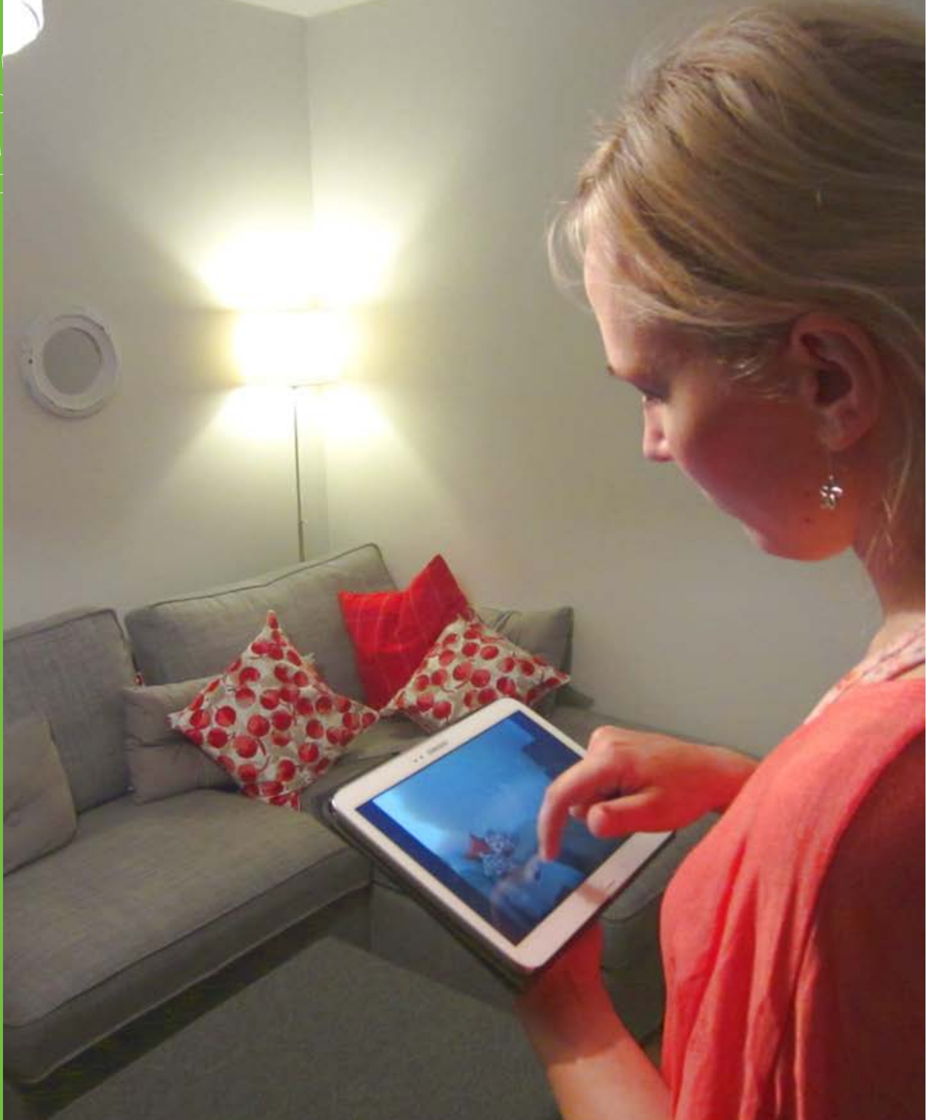


SCIENCE • TECHNOLOGY • RESEARCH HIGHLIGHTS • VISIONS

Dissertation

87

Developing augmented reality solutions through user involvement

Sanni Siltanen

VTT SCIENCE 87

Developing augmented reality solutions through user involvement

Sanni Siltanen

Thesis for the degree of Doctor of Science in Technology to be presented with due permission for public examination and criticism in Computer Science building (Konemiehentie 2, Espoo) in lecture hall T2 at Aalto University School of Science, Department of Computer Science on the 22nd of May 2015 at 12 noon.

ISBN 978-951-38-8248-8 (Soft back ed.)
ISBN 978-951-38-8249-5 (URL: http://www.vtt.fi/publications/index.jsp)

VTT Science 87

ISSN-L 2242-119X
ISSN 2242-119X (Print)
ISSN 2242-1203 (Online)

JULKAISIJA – UTGIVARE – PUBLISHER

Teknologian tutkimuskeskus VTT Oy
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

Teknologiska forskningscentralen VTT Ab
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland Ltd
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Grano Oy, Kuopio 2015

Preface

First of all, I am beholden to my adviser Dr Timo Tossavainen for his time and support. He used his spare time out of goodwill to guide me after he left the academic position and started to work for industry. I would warmly recommend him as a doctoral adviser. I was lucky to have Emeritus professor Erkki Oja as my supervisor; his always positive and supportive comments carried me through the process. I am thankful for that. I would also like to thank the pre-examiners Dr Mark Billinghurst and Dr Andreas Dünser for their valuable comments that helped me to improve this work.

I have been fortunate to work at VTT Technical Research Centre of Finland Ltd with great people. I would like to thank all my colleagues, team leaders and project managers who have facilitated this project and provided good working atmosphere during the years. Especially, I thank Principal Scientist Anu Seisto for her comments and help, Senior Scientist Kari Rainio, Senior Scientist Pekka Siltanen, Senior Scientist Petri Honkamaa and Research Scientist Katri Grenman for their proof reading and helpful comments. Special thanks also for the morning coffee group for making the world a better and funnier place.

The path of a doctoral candidate is sometimes hard; luckily I had a great companion on this travel. My co-author and "academic big sister" Dr Tiina Kymäläinen was sharing the travel, a couple of steps ahead of me.

The VTTer that I most want to thank for is Senior Scientist Paula Järvinen, a colleague and a good friend. Paula's mental support and wise advices have carried me through the difficult days.

I am also thankful to my beloved relatives, my mother Sirkka, my sister Sara, my brother Konsta and my parents in law Terttu and Jouko, for their support and help.

I am grateful for having such a great family. Doing a doctoral thesis a minor accomplishment compared to my life's greatest projects: Verneri, Heini and Aleksanteri. I am so proud of all of them.

Most of all, I thank my dear husband Antti, who has supported me more than anyone. He has always encouraged and reassured me. He has taken great responsibly for housework and let me both work and rest. I thank him from the bottom of my heart. ♥

In Klaukkala, 6.4.2015, Sanni Siltanen

Academic dissertation

Thesis advisor	Dr Timo Tossavainen ZenRobotics Ltd Helsinki, Finland
Supervising professor	Emeritus Professor Erkki Oja Department of Computer Science Aalto University School of Science Finland
Preliminary Examiners	Mark Billinghurst HIT Lab NZ University of Canterbury Christchurch New Zealand
	Andreas Dünser CSIRO – Digital Productivity Kenmore, Queensland Australia
Opponent	Professor Kaisa Väänänen-Vainio-Mattila Human-Centered Technology (IHTE) Department of Pervasive Computing Tampere University of Technology Tampere Finland

List of publications

This thesis is based on the following original publications which are referred to in the text as Paper I – Paper VII. The publications are reproduced with kind permission from the publishers.

I Kymäläinen, T. and **Siltanen, S.** 2012. Co-designing novel interior design service that utilizes augmented reality, a case study. In: Cipola-Ficarra, F. V. (Ed.) Advanced research and trends in new technologies, software, human-computer interaction, and communicability, IGI Global. Pp. 269–279.

II Kymäläinen, T. and **Siltanen, S.** 2013. User-created interior design service concepts, interfaces and outlines for augmented reality. In: Cipola-Ficarra, F. V. (Ed.) Emerging software for interactive interfaces, database, computer graphics and animation: pixels and the new excellence in communicability, cloud computing and augmented reality. Blue Herons. Pp. 28–47.

III **Siltanen, S.**, Oksman, V. and Ainasoja, M. 2013. User-centered design of augmented reality interior design service. International Journal of Arts & Sciences, Vol. 6, No. 1, pp. 547–563.

IV **Siltanen, S.**, Aikala, M., Järvinen, S. and Valjus, V. 2014. Augmented reality enriches print media and revitalizes media business. ACM Computers in Entertainment. 16 pages. In print.

V **Siltanen, S.**, Hakkarainen, M., Korkalo, O., Salonen, T., Sääski, J., Woodward, C., Kannetis, T., Perakakis, M. and Potamianos, A. 2007. Multimodal user interface for augmented assembly. Multimedia Signal Processing (MMSP). IEEE 9th Workshop on 1–3 October 2007, Crete. Pp. 78–81.

VI **Siltanen, S.** and Woodward, C. 2006. Augmented interiors with digital camera images. In: Piekarski, W. (Ed.). 7th Australasian User Interface Conference (AUIC); CRPIT. Vol. 50. ACS. Pp. 33–36.

VII **Siltanen, S.** 2015. Diminished reality for augmented reality interior design. Submitted to The Visual Computer, Springer, 18 pages.

In addition, 21 other scientific publications authored or co-authored by the writer that are listed in the list of references, support this research.

Author's contributions

In Paper I, the author was involved in the research as an augmented reality expert and took part in one of the co-creation sessions, evaluated the results relating to the use of AR in the interior design system and technological feasibility concerning augmented reality. Author participated in writing of the article.

In Paper II, the author was involved in a co-creation session together with the co-author. The author analysed the results concerning the use of augmented reality and the technical feasibility regarding user expectations. The author developed the service concepts together with the co-author.

In Paper III, the author realized, planned and analysed the co-creation sessions with consumers and professional users and the focused interviews with professional users and business actors. In addition, the author was involved analysing the results of the scenario-based survey. The author was main responsible for writing the article.

In Paper IV, the author was main responsible for writing the paper, and designing and managing the research. The author was also responsible for conceptualizing the augmented reality advertisement, augmented reality tools and hybrid media framework. The author planned, realized and analysed the focused interviews together with one co-author.

In Paper V, the author was main responsible for writing the paper and managing the research. The author was greatly involved in the design of the demo application and user interface. The author planned, realized and analysed the user tests.

In Paper VI, the author designed and developed the AR interior design application, its user interface and all functionalities. The paper was written with equal contribution by both authors. The work was supervised by Prof. Woodward.

In Paper VII, the author was the sole writer. The author developed and implemented the diminishing algorithms and methods.

Contents

List of acronyms

AR	Augmented Reality
ASR	Automatic Speech Recognition
BCI	Brain–computer interface
GDL	Goods-Dominant Logic
GPS	Global Positioning System
HMD	Head-Mounted Display
ISO	International Organization for Standardization
MR	Mixed Reality
NPR	Non-Photorealistic Rendering
PD	Participatory Design
POI	Points Of Interest
PTAM	Parallel Tracking And Mapping
RQ	Research Question
SaaS	Software as a Service
SDL	Service-Dominant Logic
SLAM	Simultaneous Localization And Mapping
SSD	Sum of Squared Differences
TAM	Technology Acceptance Model
UCD	User-Centred Design
UI	User Interface
UX	User eXperience
VR	Virtual Reality

1. Introduction

People's level of spatial perception skills varies, and viewers sometimes have difficulty understanding the relations between spatial objects. Different visualization techniques have therefore been used to help people understand 3D structures and relations (Figure 1). Traditional visualization methods are typically static and show only one viewpoint.

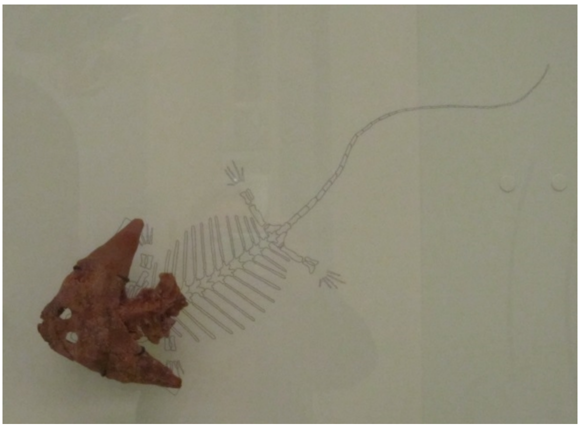


Figure 1. A fossil with an illustration of its whole skeleton helps the viewer understand the dimensions of the animal better (visualization at the Museum of Natural History, New York).

Augmented reality (AR) is a real-time technology that merges digital elements with the environment in a way that the user perceives the elements as being part of the real environment. As a 3D visualization method, AR allows the user to examine an object from any viewpoint. (Azuma 1997)

The roots of AR technology date back to the 1960s when Sutherland (1965, 1968) first presented a head-mounted display concept, *the ultimate display*, and later demonstrated the potentiality of virtual and augmented reality with a head-mounted 3D display system.

In *visual augmented reality*, graphical elements are added into the user's view (Figure 2). AR systems may stimulate other senses as well, most commonly through audio and tactile output.

Augmented reality is an efficient visualization method in application areas where the combination of real and virtual elements benefits the user, and where there is a need to enhance the user's spatial perception (Siltanen 2012, Avery, Sandor & Thomas 2009). AR can also be used to train spatial skills (Dünser et al. 2006) and to teach spatial relations (Dünser et al. 2006, Patrick, Marcus & Klinker 2009, Fedeli, Pier 2014).

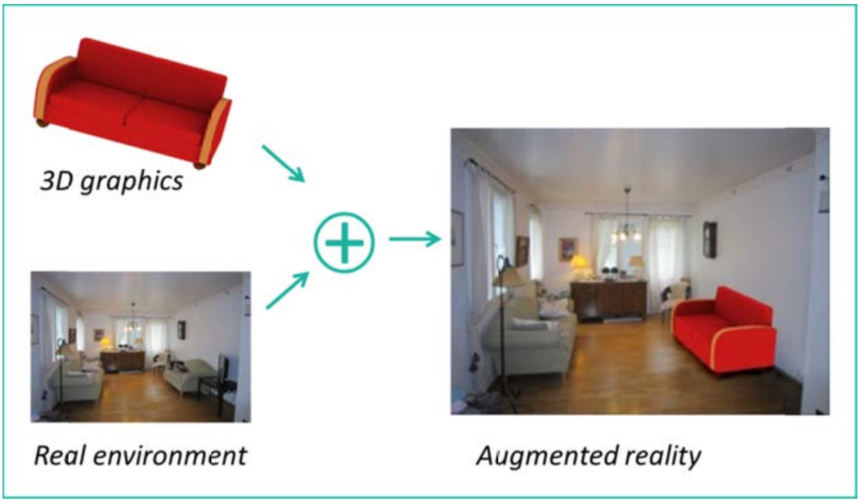


Figure 2. Augmented reality combines reality with digital content (3D graphics).

Although augmented reality has been extensively studied since the 1990s, the technology's full potential is not yet utilized (Carmigniani et al. 2011). The general focus of augmented reality research has been on enabling technologies and short-term pilots and demonstrations (Dünser, Grasset et al. 2007, Feng Zhou, Duh et al. 2008). User based experiments have been rare in AR development (Swan and Gabbard 2005). AR is seldom used in everyday applications by ordinary consumers. In this thesis, the author considers different issues that have an influence on AR becoming everyday technology especially in interior design application area.

The idea for this research emerged when the author gave a keynote talk *"Augmented reality beyond the hype – what is it good for?"* at the MUSCLE International Workshop on Computational Intelligence for Multimedia Understanding in 2011 (Siltanen 2011). Although there are many application areas where AR would be beneficial, it is not commonly used in practical consumer-level applications. This work aims to find reasons for this. 'Practical applications' means here that we exclude games, for example. Consumer-level means that we are interested in ordinary people and mass market applications as opposed to specialized professional use of AR by experts. In addition, our aim is to find ways to enhance augmented reality and develop methods and algorithms that support consumer-level visualization applications.

1.1 Background and research environment

Besides the work described in this thesis, the author has studied several other aspects of AR. This additional research supports the work described in this thesis and forms a solid foundation upon which this work is built. The present thesis is, however, independent of the additional, supporting work.

The supporting research consists of:

- Tracking solutions
  - (Siltanen, Hakkarainen & Honkamaa 2007)
  - (Honkamaa et al. 2007)
- Mobile interactions
  - (Siltanen, Hyväkkä 2006)
  - (Ailisto et al. 2007)
  - (Siltanen, Woodward, Valli, Honkamaa and Rauber 2008)
- AR solutions for building, construction and interior design
  - (Siltanen 2013)
  - (Pinto Seppä et al. 2007)
  - (Kähkönen, Hyväkkä, Porkka, Siltanen and Woodward 2008)
  - (Woodward et al. 2007b)
  - (Woodward et al. 2007a)
  - (Oksman, Kulju and Siltanen 2011)
- AR research for maintenance and assembly tasks
  - (Sääski, Salonen, Siltanen, Hakkarainen and Woodward 2007)
  - (Salonen et al. 2007)
  - (Sääski et al. 2008)
  - (Azpiazu et al. 2011)
- Mixed reality and hybrid media solutions
  - (Siltanen and Aikala 2012)
  - (Välkkynen et al. 2013)
- Diminished reality and marker hiding methods
  - (Korkalo, Aittala and Siltanen 2010)
  - (Siltanen 2006)
  - (Siltanen, Saraspää and Karvonen 2014)
- Overview of the AR field
  - (Siltanen 2012)

To date, the author and other researchers have presented a considerable number of demos and pilots, and the technology has been developed in many aspects. In

Chapter 2 we provide a thorough overview of the AR field and elucidate the conceptual background of augmented reality. The chapter also clarifies the terminology and technical framework of AR. Our application and algorithm development, described later in Chapter 4, is built upon this framework. In addition, the technical work is also based on in-depth knowledge of the augmented reality field gained during earlier AR research and development.

Although the technology itself is mature, certain human factors need to be overcome before AR systems can become adopted for commonplace use (van Krevelen and Poelman 2010). This became apparent during our previous research as well. In this work, we consider the human–technology interaction related factors that need to be addressed in order for AR to make a breakthrough at the consumer level. We both identify these factors and develop technical solutions to them.

A *hype cycle* [1] provides a cross-industry perspective on the development and trends of emerging technologies. It illustrates how and when technologies move beyond the hype, offer practical benefits and become widely accepted (Gartner 2014).

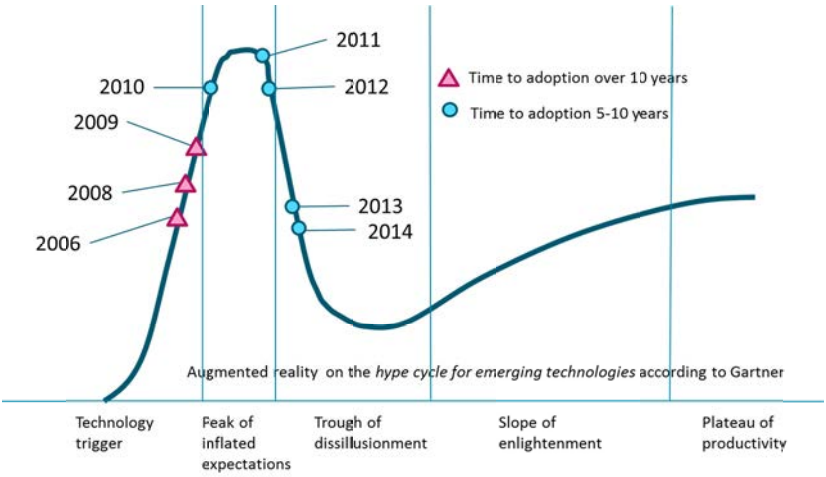


Figure 3. Augmented reality on the hype cycle according to Gartner.

Figure 3 shows how augmented reality technology has developed according to Gartner[2]. AR is treated here as a single technology; however, in practice there is deviation in the maturity of different application areas of augmented reality. At present, AR is in the stage termed the *trough of disillusionment* (LeHong, Fenn

[1] http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp
[2] http://www.gartner.com/

and Leeb-du Toit 2014). In this work, we consider factors that would enable AR to transfer to the *plateau of productivity*.

The author has been a member of VTT's augmented reality team[3], which has created ALVAR[4], A Library for Virtual and Augmented Reality (Appendix C). Most of the work reported in this thesis is either built using ALVAR or contributes to ALVAR.

1.2 Objectives and scope

The objective of this work is to advance AR towards commonplace consumer applications and get it to the *plateau of productivity* stage on the hype cycle. It is apparent that this only is possible if user-based experimentation is applied to augmented reality development (Swan and Gabbard 2005).

The author's earlier, comprehensive work in the AR field showed that getting AR technology into everyday use in consumer-level applications is laborious (see page 13 for references). It also revealed that besides technology development, business factors and human factors affecting acceptance of the technology must be considered. In other words, adoption of the technology must be considered from a wide perspective. Thus, the aim is threefold: firstly to **understand the human factors** affecting acceptance of AR technology and ***involve users in the design process***, secondly to ***develop applications and technical solutions*** for AR that support these factors and, thirdly, to discuss some of the ***economic factors*** affecting the wide use of the AR technology.

Considering all this, the *research problem* is formulated as ***How can user involvement be utilized in developing more effective AR experiences?*** The research problem is further divided into the following research questions (RQs):

RQ1a: How to involve users in the design process to create more effective AR experiences?
RQ2a: What are the user expectations regarding AR interior design?
RQ3a: Which technical solutions fulfil the user expectations and improve the user experience of AR?

In addition to these three main research questions we discuss the following:

RQ4a: Which business ecosystem factors support the wide utilization of the AR technology?

[3] www.vtt.fi/multimedia (The actual name of the team and its composition has varied.)
[4] www.vtt.fi/multimedia/alvar.html

This research deals with ***ad-hoc methods*** in an ***unknown environment***, and ***consumer-level applications***. We are especially interested in ***visual augmented reality***. Our focus application area is ***interior design,*** thus we concentrate on ***indoor augmentations***. In addition, we also study the ***AR in assembly,*** and ***hybrid media*** application area from the AR advertising perspective. Besides interior design, we consider the wider ambient home design[5] concept. Furthermore, we are interested in ***human factors*** i.e. user expectations and user experience, ***business prospects*** of AR services, and ***application and technology development*** (Figure 4).

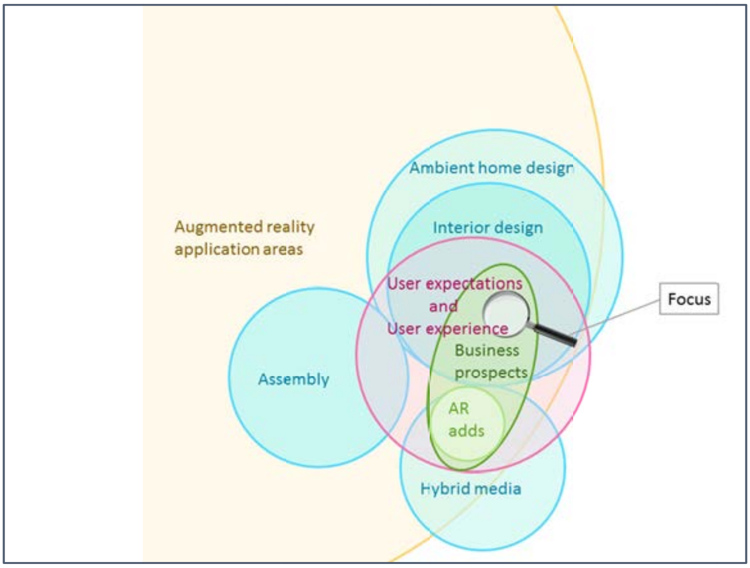


Figure 4. Venn diagram of the focus of the work

The research focus is on ***the user viewpoint of AR applications***. Thus, while we acknowledge authoring as being an important and necessary part of the hybrid media system (see Figure 22, page 53), further examination of authoring is omitted from this study. Furthermore, the focus is on software issues; hardware and devices are thus outside the scope of this work. In addition, although this research is concerned solely with visual augmentations, we recognize that augmented reality is not limited to visual input.

[5] Ambient home design means the design of the aesthetic home environment; including interior design, lighting design, floor and wall covering, textiles etc.

1.3 Research process and contribution of research papers

The research contribution of this work falls into three categories (Figure 5):

- Identifying user expectations and other factors affecting the viability and acceptance of AR technology (the blocks on the left)
- Application development to improve the user experience of AR, and (the middle block)
- Technical development to improve specific features of AR applications (the block on the right).

Papers I, II and III study the human factors – user experience and user expectations – affecting the adoption of AR technology in consumer-level AR interior design services. User expectations are best revealed together with users, and these paper present studies with user involvement. The studies provide general guidelines for the construction of such services and a list of important features of interior design.

Papers III and IV examine business ecosystem factors in interior design and in hybrid media advertising, respectively. In these papers several actors are involved in the early design of the digital service. Some business ecosystem factors concerning interior design services also are discussed in Papers I and II.

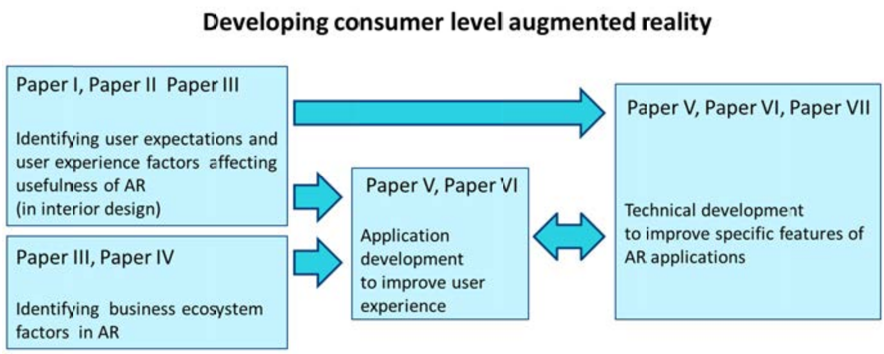


Figure 5. Contribution of each research paper.

Papers V and VI report application development; Paper V in augmented reality assembly and Paper VI in interior design. Both applications are developed with the aim of improving the user experience (UX) of augmented reality.

Papers V, VI and VII contribute to the technical development of AR. They present algorithms, methods and implementations of specific features of AR previously identified as important in Papers I, II, III and IV, or during application development (Papers V and VI). On the other hand, the developed features are integrated to the applications.

Papers VI and VII contribute to AR in the interior design application area, and Paper V contributes to the use of AR for assembly instructions. Paper V not only describes technical work but also illustrates the importance of taking user preferences into account in system design. Furthermore, paper V studies multimodal user interfaces, and thus brings a new viewpoint to the work.

The storyline of the thesis starts with identifying important aspects and features of AR technology, and then moves through application development to technical development (Figure 5).

Author's research shows that involving users in co-design helps to identify both critical features of AR service and other important factors that affect user experience. Thus user involvement affects adoption and popularity i.e. viability of the service. This research also shows that understanding business ecosystem helps in developing successful AR services. In addition, the author presents application and algorithm development to support critical features of consumer-level AR applications, with a focus on interior design. Specifically, she develops diminished reality technology for removing existing furniture virtually from the view.

Finally, Section 4.3 presents real-life examples of AR interior design carried out using the developed technology, thus confirming the validity and quality of the research.

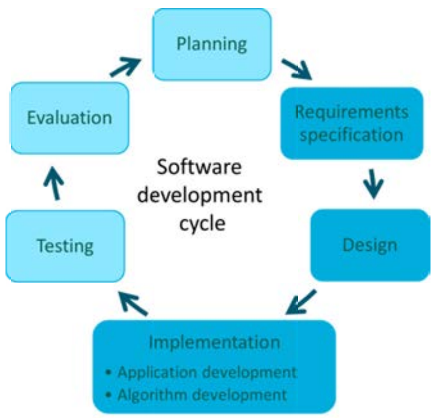


Figure 6. Simplified software development cycle; the main contribution of this work in the software development cycle is marked with darker blue.

Software development is usually an iterative and incremental process. An illustration of the simplified software development cycle is presented in Figure 6. As an academic dissertation the focus in this work is on the research question rather than product development, therefore some parts of the cycle are iterated and some are covered superficially. Certain parts are considered from multiple application domain viewpoints and other parts concentrate on a single application domain. The users are involved at different stages of the process. This work concentrates on the "first half" of the software development cycle; the main contribution falls in **requirements specification, design and implementation phases** (Figure 6). In the implementation phase the work contributes both on application development and algorithm development. The initial planning process is not explicitly described although it is in the background of the work. It goes without saying that user testing and evaluation are essential components for assessing how the developed system actually meets user needs. However, in order to focus on the presented research questions, testing and evaluation are covered in this thesis in a more informal manner and have to be left for further studies.

In commercial software development, the development often follows more strictly some established software development process. Moreover, in real software development the cycle is iterated several times.

1.4 Dissertation structure

The introductory part of this work is organized as follows:

Chapter 2 provides an overview of the conceptual background of augmented reality and clarifies the terminology and technical framework of the AR field.

Chapter 3 focuses on the user aspects – user experience, expectations and requirements – of augmented reality. In the first section (Section 3.1), the author reviews the conceptual background of user-centred and participatory methods. Then an overview of the applied methods and their research aims is given (Section 3.2). Thereafter, the author presents five case studies (Sections 3.3–3.7). The presented research identifies factors delaying the adoption of AR in commonplace consumer-level applications, with a focus on interior design. The author also considers business ecosystem factors affecting the mass-market adoption of AR in two application areas: interior design and hybrid media. (Papers I, II, III and IV)

Chapter 4 addresses the key issues of AR application development towards commonplace technology and describe authors work on application and algorithm development. It focuses on selected bottlenecks identified during the preceding work (results from Chapter 3) and presents technical and algorithmic solutions for resolving them. The first section (4.1) describes research work in the area of augmented reality assembly. Section 4.2 focuses on the AR interior design application area. Section 4.2.2 describes algorithm development in diminished reality. The chapter ends with real-life examples of AR interior design (Section 4.3). (Papers V, VI and VII)

Chapter 5 concludes together the outcomes of all studies presented in Chapters 3 and 4 and answers all research questions.

In Chapter 6, the author concludes her research and examines how it contributes to the goal of bringing AR into consumer-level applications. In addition, Chapter 6 gives guidelines for AR application development and discusses the future of the AR field.

Appendices A and B present the use case scenarios used in the studies presented in Chapter 3. The ALVAR library is presented in Appendix C. Original research papers I–VII are also included.

2. Conceptual background of augmented reality

Augmented reality means a system where virtual elements are blended into the real world to *enhance the user's perception* (Caudell and Mizell 1992). A *mixed reality* (MR) system merges the real world and virtual worlds to produce a new environment where *physical and digital objects co-exist and interact* (Milgram, Takemura, Utsumi and Kishino 1994). *Reality* means here the physical environment; in this context often the visible environment as seen directly or through a video display. An augmented reality system is identified by three characteristics: it *combines the real and the virtual*, it is *interactive in real time* and it is *registered in 3D* (Azuma 1997, Azuma et al. 2001).

In addition to combining virtual and real elements, a digital system can alter the environment in other ways as well. In *mediated reality,* a person's perception of reality is manipulated (Figure 7). Besides adding virtual elements (i.e. *augmented reality*), the system may remove something (i.e. *diminished reality*) or alter the reality in some other way (i.e. *modulated reality*) (Mann 2002).

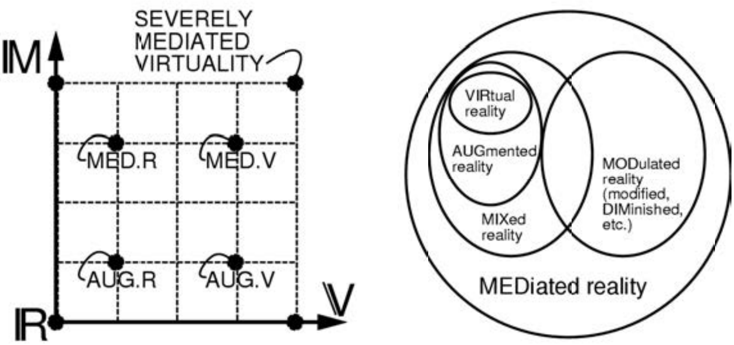


Figure 7. Mann's reality–virtuality–mediality continuum (Mann 2002). Reality (**R**) is at the origin, (**V**) is the virtuality continuum and (**M**) the mediality continuum.

Virtual reality (VR) is an immersive environment simulated by a computer. The simplest form of virtual reality is a 3D scene that the user can explore interactively from a personal computer, usually with a keyboard or mouse. Sophisticated VR systems consist of wrap-around display screens, actual VR rooms, wearable computers, haptic devices, joysticks, etc.

Augmented virtuality is a system where a virtual environment is augmented with real world components; for instance by adding live video feeds to the virtual world, such as SecondLife[6].

Augmented reality applications mostly focus on *visual augmented reality* and, to some extent, on audio and tactile sensations in the form of haptic feedback.

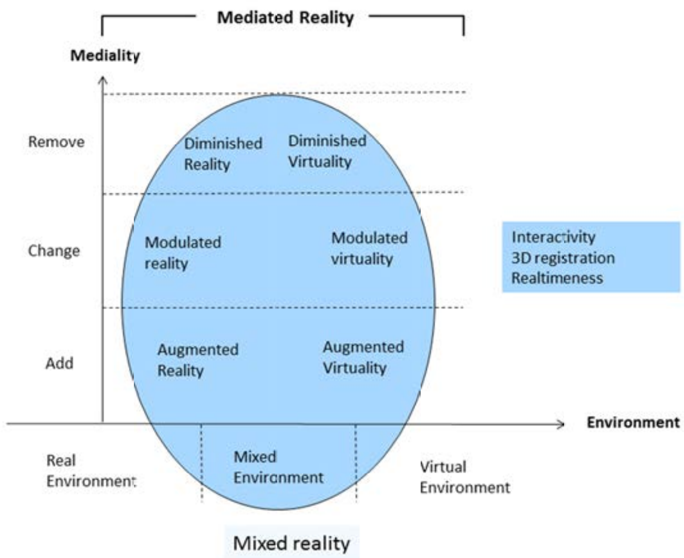


Figure 8. Mediated reality taxonomy (Siltanen 2012).

We summarize the taxonomy for *mediated reality* in Figure 8 (Siltanen 2012). From left to right we have the reality–virtuality environment axis, the middle of which contains all combinations of the real and virtual, the *mixed environments*. The mediality axis is enumerable; we can add, remove or change its contents. *Mediated reality* consists of all types of mediality in mixed environments. The subgroup of mediated reality, which includes interaction, 3D registration and real-time components, is *mixed reality*.

[6] http://secondlife.com/

A basic augmented reality system consists of a camera, a computational unit and a display. The camera captures an image, and then the system augments virtual objects on top of the image and displays the result.

Figure 9. Example of a basic augmented reality system; the camera view is augmented on a tablet PC.

Figure 9 illustrates an example of a basic augmented reality system on a tablet PC; the environment, as seen by the camera, is augmented and displayed on screen. AR systems can run on a PC, laptop, tablet PC, mobile phone or other computational unit. Depending on the application, they can use a digital camera, a web camera or the built-in camera of the computational unit. They can use a head-mounted display, see-through display, external display or the built-in display of the computational unit. Alternatively, the system may project the augmentation onto the real world or use a stereo display. The appropriate setup depends on the application and environment. At present, a tablet PC is an ideal device for consumer applications as it has an integrated camera and relatively large display.

In many AR applications the user moves virtual objects around or otherwise manipulates them. This kind of interaction is difficult in live video mode, especially with mobile devices. One solution is to pause i.e. “freeze” the image while the user interacts with the system, and thereafter resume back to live video mode (Lee et al. 2009; Zöllner, Becker and Keil 2010). Long-time use of mobile AR device such as tablet PC is tiresome, when the user needs to hold the device in the air. In the paused, *still image mode*, the user is able to lay down the device and investigate the augmentation with time (Woodward, Kuula, Honkamaa, Hakkarainen and Kemppi 2014). Some applications may rely solely on snapshots i.e. augmented still images (Keil, Zöllner, Becker et al. 2011).

It is debatable whether the still image augmentation is considered augmented reality or not, because it has a fixed view point (or a set of fixed viewpoints when a set of still images are used) and a fixed view direction. This is especially arguable when still image mode is the only mode in the application. AR telescope or AR web camera applications also have fixed viewpoint, and limited or fixed view direction. Some visualisation applications show fixed augmentation; the user interactions with the system are limited or non-existent. Some mobile guidance applications show information for navigation purposes, the location of e.g. a restaurant can be approximate and only associated with the building; the 3D registration is loose and has some restrictions and in many cases no interactivity is present. It is rather a philosophical question how much restrictions there can be in a system to be still considered mixed or augmented reality.

The author considers still image based augmentations as augmented reality, if the virtual elements are augmented in real environment in 3D and the user interaction happens in real time, that is, the user is able to e.g. move elements in real time and there is no off-line processing involved. In this case the application fulfils the definition of augmented reality as defined in Figure 8.

2.1 Aligning virtual and real elements

The essential difference between AR and other basic image and video manipulation tools is that in augmented reality virtual objects are manipulated in *3D coordinates* instead of 2D image coordinates, and that the manipulations happen *in real-time*. In order to be able to do this, the system needs to know where the user is and what the user is looking at. Normally, the user explores the environment through a display that portrays the camera image with augmentation. Thus, in practice the system needs to calculate the pose of the camera. *Pose* means the *six degrees of freedom* (6 DOF) position, i.e. the 3D location and 3D orientation of an object, and *tracking* in the augmented reality context means calculating the pose of a camera continuously in real time. Tracking is a core functionality of an augmented reality system.

In *computer graphics*, the virtual scene is projected through a virtual camera and this projection is then rendered on screen (see e.g. Shirley, Ashikhmin and Marschner 2009: 142–155). The trick in augmented reality is to use a virtual camera identical to the system's real camera. This way, the virtual objects in the scene are projected in the same way as real objects, and the result is convincing (see e.g. Siltanen 2012: 55). In order to be able to mimic the real camera, the system needs to know the optical characteristics of the camera. The optical characteristics are presented with *camera parameters*. The system needs to know the camera parameters also to be able to track the camera accurately. The process of identifying these characteristics is called *camera calibration*. With a calibrated camera the system is able to render virtual objects in the correct place. (See e.g. Szeliski

2010: 320–334.) Camera calibration can be part of the AR system, and many AR tools (e.g. ALVAR[7]) have calibration functionality.

Researchers in computer vision, robotics and photogrammetry have developed a considerable number of different tracking methods. Since the camera is already part of the system in most augmented reality setups, *visual tracking methods* are of special interest in AR. Visual tracking methods use computer vision methods to deduce the pose of the camera. Visual tracking is also called *camera (-based) tracking* or *optical tracking*.

One approach to tracking is to add an effortlessly detectable predefined sign in the environment. A sign or a picture that can easily be detected from a video image using image processing, pattern recognition or computer vision techniques, is called a *marker*. In *marker-based tracking* the pose calculation relies on marker detection. In general, it is impossible to deduce the correct scale solely based on visual observations (see e.g. Hartley and Zisserman 2000: 157). However with a marker of *known size* an AR system is able to calculate the correct scale.

Other approaches for visual tracking are *feature-based* and *model-based* methods. In model-based tracking, the system contains a 3D model of the scene or part of the scene (Bleser, Wuest and Stricker 2006, Makita 2014). It compares visual observations with the model and finds the best match thus defining the pose. In feature-based tracking, the system detects optical features in the images and learns the environment based on observations of movements between frames (see e.g. Klein and Murray 2007, Rosten, Porter and Drummond 2010, Dong, Zhang, Jia and Bao 2014).

Even though the mainstream development in visual tracking research is towards model- and feature-based tracking, markers are still widely used in augmented and mixed reality (e.g. Celozzi, Paravati and Lamberti 2010, Jun, Yue and Qing 2010, Santos, Stork, Buaes, Pereira and Jorge 2010). Feature tracking and marker-based tracking are mutually non-exclusive; hybrid methods can combine marker-based and feature-based tracking. Markers may encode information or at least have an identity. This enables a system to attach certain objects or interactions to the markers.

Hybrid tracking means that the system combines two or more tracking methods; typically visual tracking and sensors in AR applications (see e.g. Naimark and Foxlin 2002, Reitmayr and Drummond 2007, Honkamaa, Siltanen, Jäppinen, Woodward and Korkalo 2007, Kurz and BenHimane 2011).

The basic idea of pose calculation is the same in all visual tracking methods. The system detects known “things” from the image (marker corners, features, edges, lines, model parts). It knows the real 3D physical relations between them (e.g. size of the marker, relative position of the features, 3D model) or it deduces the relations during tracking. See, for example, (Szeliski 2010: 321–326 and 363–

[7] www.vtt.fi/multimedia/alvar.html, See also Appendix C.

369, Hartley and Zisserman 2000: 153–166) for more details on pose calculation and tracking methods.

Augmented reality software libraries provide a good base for starting AR application development (e.g. ARToolKit[8] and ALVAR).

Adding a tracking module – which is pretty straightforward task – to a still-image-based application, would transform it to a real-time visualization application. This is also why the author does not feel urged to separate still-image applications from other augmented reality applications, if the application otherwise fulfils the definition of augmented reality.

2.2 Overview of augmented reality application areas

AR benefits all tasks where real-time 3D visualization of information on site helps the human operator. It is well suited for on-site visualization both indoors and outdoors, for visual guidance in assembly, maintenance and training. Augmented reality enables interactive games and new forms of advertising. This subsection provides an overview of different application areas of augmented reality, with notions on special issues in the presented application areas.

Augmented reality on mobile devices, *mobile augmented reality* (MAR), has great potential to alter the way people interact with the environment and with each other (MIT 2007, Fenn 2010, Liao and Humphreys 2014, Ajanki et al. 2011).

AR is used for visualization of building projects on-site (Woodward et al. 2010) and over the internet with an interactive pan-tilt-zoom camera (Woodward et al. 2007b). With a connection to the BIM (Building Information Model), the user can interact with materials and browse through the timeline of a construction project, as our research team at VTT has demonstrated (Kähkönen et al. 2008). See also (Rankohi and Waugh 2013). AR helps also facility management of the build environment (Irizarry, Gheisari, Williams and Walker 2013).

In assembly, AR applications can show assembly instructions to the assembler at each stage of work. The system can display the instructions on a head-mounted display as, for example, in our assembly demonstration (Sääski et al. 2008) on a mobile phone (Billinghurst, Hakkarainen and Woodward 2008) or on a PC display (Salonen et al. 2009). Besides a keypad the user can interact with an assembly system using voice commands and gestures as we have demonstrated (Paper V and Salonen et al. 2007).

In maintenance, a mobile augmented reality system can provide workers with relevant information from a database (Savioja, Järvinen, Karhela, Siltanen and Woodward 2007). Augmented instructions have been proven to be helpful and satisfying to maintenance workers (Abate, Narducci and Ricciardi 2013, Henderson and Feiner 2009). A mobile device is a good choice for displaying information in many cases. However, in the case of more hands-on assembly maintenance

[8] http://www.artoolworks.com/products/

tasks, a head-mounted display is often a better choice (Henderson and Feiner 2011b, Henderson and Feiner 2011a).

Augmented reality is used to enrich print media. Several newspapers have published AR content that the user can see with a mobile AR application such as Layar App[9]. In addition, several books have augmented digital content (Billinghurst, Kato and Poupyrev 2001, Evans 2008, Green 2010, Lehtinen, Mäkijärvi and Inkeri 2010, Moffet 2010, Mash 2010).

Augmented reality is by nature ideally suited, for example, to gaming, learning motivation (Cascales, Laguna, Perez-Lopez, Perona and Contero 2013, Di Serio, Ibáñez and Kloos 2013) and advertising. In these fields, application development often focuses on the user interface, user interactions, enjoyment, playfulness, smoothness of use, etc. Technology is often used in a creative way in these applications, and user experience is typically a major priority. The New Media Consortium[10] (NMC) sees the importance of AR in education as increasing (Johnson, Smith, Levine and Haywood 2010).

AR provides means to link information to real-world objects and specific locations. AR content is used in AR browsers, aka world browsers (e.g. Layar[11], Junaio[12], and Wikitude[13]), and other location-based services for visualizing a variety of different data. These applications use AR to show nearby restaurants, metro stations, shops, cafes, offers and museums. Location-based AR applications can provide additional information on buildings, history, bus timetables and restaurant menus, and help with navigation. AR location-based applications let the user define tags and points-of-interest and link them to Facebook, Twitter, Foursquare and other social media networks. Grubert, Langlotz and Grasset (2011) identify user experience factors – user interface design, amount and quality of data, system performance – as key factors affecting long-term use of these applications.

Augmented reality visualization is used to support other tasks in the area of robotics, for example for collision-free robot programming (Chong, Ong, Nee and Youcef-Youmi 2009) and for improving robotic operator performance (Maida, Bowen and Pace 2007, Stone, Bisantz, LLinas and Paquet 2008). It also benefits many medical applications, such as laparoscopic surgery (Bichlmeier, Heining, Rustaee and Navab 2007, Shekhar et al. 2010, Kang et al. 2014).

Interior design is another application area were AR is beneficial (Wang 2009, Caruso, Re, Carulli and Bordegoni 2014). AR enables users to *virtually test how a piece of furniture fits in their own home* (Figure 10). Positioning virtual objects is easier on a still image or in a paused live video (Lee et al. 2009). Augmented reality interior design applications may use still images. Nonetheless, the user

---

[9] https://www.layar.com/products/app/
[10] http://www.nmc.org/about
[11] https://www.layar.com
[12] http://www.junaio.com
[13] http://www.wikitude.com

interactions with virtual elements happen in real-time (e.g. positioning them), and the augmentation is realized in 3D coordinates. (Paper VI) Another possibility is to combine the still image approach with video; the user pauses the video to position furniture in a still image, but thereafter the augmentation is carried out in live video[14] similar to freeze technique described by Lee et al. (2009). Naturally, the application can use live video only (Honkamaa, Jäppinen and Woodward 2007).

Figure 10. Augmented reality interior design enables the users to test furniture at own home.

2.3 Interactions between virtual and physical objects

Virtual objects interact with real objects; they may collide, occlude or overlap each other. *Occlusion* means a situation where an object is in front of another object, and hides it from the view. As the augmentation is rendered on the top of the camera image, occlusion is a problem when one needs to augment a virtual object (partly) behind a physical object.

In *foreground masking* the occluding object is masked and only visible parts of the virtual object are augmented (Pilet, Lepetit and Fua 2007, Boun Vinh, Kakuta, Kawakami, Oishi and Ikeuchi. 2010, Abate, Narducci and Ricciardi 2014). The system can detect occluding moving objects based on motion and background detection and segmentation methods (Boun Vinh et al. 2010, Chen, Granier, Lin, and Peng 2010).

---

[14] For example, Vivid Works' LiveAR extension to VividAR works this way: https://www.youtube.com/watch?v=Ip5plNOT20U (see also page 84).

Depth cameras can be used to detect occluding objects from the foreground (Li, Li, Zhang, Li and Wang 2013, Corbett-Davies, Dünser, Green and Clark 2013) (Figure 11). Few hardware solutions (e.g. Microsoft Kinect[15]) have integrated depth and RGB cameras.

When the occluding objects are contextually unimportant, the application can use diminished reality to overcome occlusion; the occluding objects are removed virtually and the whole virtual object is augmented (Figure 11). A mask used for diminished reality can be approximate as long as it totally covers the diminished object (Avery, Piekarski and Thomas 2007), whereas a mask used to define a foreground object needs to be accurate. We discuss diminished reality more in the next section (Section 2.4).

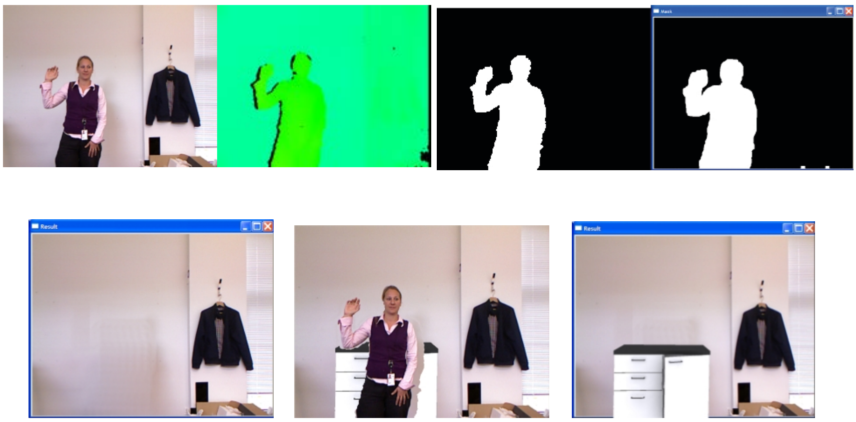


Figure 11. Use of a depth camera to diminish a foreground object. Top (left to right): original RGB image; false-colour depth image; thresholded mask and dilated mask. Bottom (left to right): diminished version of original image; augmented image with mask used to mask out the foreground object; augmentation on the diminished image (Siltanen 2012).

Simple transparency means that occluding or occluded objects are made transparent. This approach gives a hint of occlusion, but the order of objects may be confusing (Livingston et al. 2003, Furmanski, Azuma and Daily 2002).

In *X-ray vision* the real environment and the augmentation are blended in a manner that creates an illusion of seeing through or inside a real object. X-ray vision is an effective and useful method for outdoor inspection and maintenance tasks of underground infrastructure, such as voltage bands and gas pipes (Schall, Mendez and Schmalstieg 2008, Schall et al. 2009, Kalkofen, Mendez and

[15] http://www.microsoft.com/en-us/kinectforwindows/

Schmalstieg 2007), as well as in laparoscopic surgery applications for visualizing tomography images on patients (Shekhar et al. 2010).

Perception of the distance and depth order of objects is improved with tunnel frustum cut-out and rendering of the edges of the occluding object (Bane and Höllerer 2004, Avery, Sandor and Thomas 2009). However, users tend to underestimate the distance to the occluded object in X-ray vision even with depth cues (Dey, Cunningham and Sandor 2010). Besides edges, other salient features such as hue, luminosity and motion can be maintained to provide richer content for the occluding object (Sandor, Cunningham, Dey and Mattila 2010a). Another possible approach is to compress the occluding object such that it appears to 'melt' onto the ground (or floor) (Sandor et al. 2010b).

Collision detection between a real and a virtual object is challenging because the application does not know the boundaries of real objects. Therefore, AR applications seldom have any mechanism for collision prevention and users may, for example, move virtual objects through real ones.

Systems that are able to detect and prevent collisions with moving physical objects typically use multi-camera systems (Yoon and Jung 2009), depth cameras (Seo and Lee 2013) or a stationary setup (Murase, Ogi, Saito, Koyama and Biru 2008). It is also possible to use a model-based approach, which requires a-priori knowledge, i.e. the model (Breen, Whitaker, Rose and Tuceryan 1996).

In some applications, such as games and other applications using gesture interface, collision detection reduces to 2D (Lee, Lee, Kim and Lee 2010, Paper V). Another approach for collision prevention is to mark collision-free areas beforehand (Chong et al. 2009).

In order to perceive seamless integration of the virtual and real world, a system should also consider real shadows on virtual objects. When foreground objects are divided into actual objects and shadows, the application is able to recast shadows of real foreground objects on virtual objects (Boun Vinh et al. 2010, Pilet, Lepetit and Fua 2007).

2.4 Diminished reality

Augmented reality applications are often used for visualizing changes. Users may wish to remove an existing object or replace it with a new one. If a virtual object is augmented such that it even partially overlaps an existing object, the illusion of augmented coexistence is lost, and the user experience is damaged (Figure 12). This problem can be overcome by physically removing the real interfering object before augmentation. However, the essential point of using AR is to enable visualizations without requiring physical action. Therefore, a digital solution is preferred. One possibility is to use *diminished reality*, i.e. to virtually remove real objects from view.

Interior design is an application area where diminishing capability is especially valuable (Paper III, Pinto Seppä et al. 2007).

Figure 12. Example of diminished reality. Left to right: original image; augmentation over existing object; diminished image; augmentation over diminished image (Siltanen 2012).

In image processing, *image inpainting* means restoring missing or damaged image regions, or covering obtrusive parts of an image in such a way that the processed regions resemble the rest of the image. Augmented reality researchers often use the terms *diminishing*, *diminished reality*, *object hiding* and *object removal* for the same function. The term *texture generation* is also used in the same context.

Image inpainting is often used for offline video editing and for image processing in image manipulation tools where the speed of the method is not critical. A number of inpainting methods that are suitable for offline processing have been presented (Wang 2008, Li, Wang, Zhang and Wu 2010, Sen-Ching, Cheung and Venkatesh 2006, Criminisi, Perez and Toyama 2004, Bornemann and März 2007, Kokaram 2002, Ting, Chen, Liu and Tang 2007, Bertalmio, Sapiro, Caselles and Ballester 2000, Yamauchi, Haber and Seidel 2003, Allene and Paragios 2006).

Marker hiding is a special case of diminished reality. The simplest way of hiding a marker is to augment a static image over it. Another simple method is to interpolate values from the area surrounding the marker to cover it. Interpolation methods are very fast and simple, and require little memory and processing capacity. The drawback is that they only preserve colours, not textures. (See e.g. Telea 2004) Interpolation can be combined with texture generation, and texture can be created in world coordinates in order to achieve a better visual result (Siltanen 2006, Siltanen 2012). The ALVAR library contains a real-time implementation of such a marker hiding method (Siltanen 2006).

Real-time marker hiding methods may also adapt to illumination changes, as presented by Korkalo, Aittala and Siltanen (2010). Also Kawai, Yamasaki, Sato and Yokoya (2012) have presented a marker hiding method that adapts to changes in lighting. Their method casts detected shadows over the hidden marker area.

Another possible approach for real-time performance is to use a client–server system with remote computing facilities to implement time-consuming inpainting for mobile and wearable solutions (Lee 2009).

Exemplar-based inpainting methods use samples from the source area to fill-in the diminished area (Criminisi, Perez and Toyama 2003). Researchers have applied exemplar-based inpainting methods for diminished reality (Kawai, Sato and Yokoya 2014, Herling and Broll 2012).

AR applications contain 3D information on the environment. Thus, for example, marker hiding can be carried out in marker plane coordinates (Korkalo et. al 2010, Kawai et al. 2012, Siltanen 2006). Other planar objects can also be diminished using 3D coordinates (Siltanen 2012).

For indoor scenes, Kawai, Sato and Yokoya (2014) propose rectifying planes in keyframes and carrying out inpainting in the rectified planes, and then, in the subsequent frames, mapping the inpainting textures according to the current pose (i.e. position and orientation).

Diminished reality applications may aim for situations where it is possible to have information on background textures and use multiple cameras (Enomoto and Saito 2007, Jarusirisawad, Hosokawa and Saito 2010). The background can also be reconstructed from a collection of images (Zhuwen, Yuxi, Jiaming and Loong-Fah 2013).

In a typical augmented reality scenario the user utilizes the application in an unforeseen environment and the items in the environment are unknown. Therefore, a conventional approach is to exploit user interaction to define the object (Zokai, Esteve, Genc and Navab 2003). A straightforward and commonly used approach is that the user indicates the object across several keyframes, and a 3D volume defining the area of the object is calculated from these keyframes (Lepetit and Berger 2001). The user may also indicate the object by drawing a loop around it (Herling and Broll 2010). This is especially convenient with touchscreen devices.

After the user has indicated the diminished area in the image plane, the application must track the area or the object to be diminished in subsequent images. Herling and Broll (2010) use an active contour algorithm (Kass, Witkin and Terzopoulos 1988) for this. Object tracking can rely on motion detection and tracking, image segmentation, feature detection and tracking, or any other real-time object tracking method (Siltanen 2012).

An augmented reality system with haptic feedback is a special case; the system knows the visually disturbing object (the haptic device) beforehand, the pose of the object is known, and users can even influence the appearance of the object to be able detect it easily (Cosco, Garre, Bruno, Muzzupappa and Otaduy 2009, Inami, Kawakami and Tachi 2003).

3. Investigating requirements for AR services

In this chapter, we begin to address the major research question of the thesis: how to advance AR towards commonplace consumer applications. We describe our work on advancing AR towards wide use with participatory and user-centred design. Our work was twofold; we studied both user expectations and business ecosystems in order to identify factors that are critical for a widely adoptable AR service. We investigated two augmented reality application areas, home design and hybrid media.

First we review the conceptual background. We then discuss our five distinct studies; their methods, implementation and the outcomes of each study.

3.1 Conceptual background of user cognizance in design

The value of user involvement in the software development process is well known. Involving users at the early stages of the process prevents costly changes later on (Damodaran 1996, Norman 1998). User involvement also ensures that the software features meet the user's needs, which in turn ensures greater acceptance and better usability (Kujala 2003, Mao, Vredenburg, Smith and Carey 2005).

The importance of user involvement is independent of software development models or methodologies. It is used, for example, in the waterfall, spiral and agile (Näkki, Koskela and Pikkarainen 2011) software development approaches. Users can contribute the software development process at different stages, from early concept design to testing the actual software. (Butt and Wan Ahmad 2012, Bano and Zowghi 2013)

The philosophy behind *user-centred design* (UCD) is to develop a system in a direction that allows its users to interact with it in the way they want or need. *Human-centred design* (ISO 9241-210, 2010) is often used as a synonym for user-centred design. In UCD the needs, abilities and wishes of the end-users are taken into account at each stage of the design process (Sharp, Rogers and Preece 2007). User involvement is especially useful in the early stages of development; it speeds up the development process and promotes service success (Alam and Perry 2002, Carbonell, Rodríguez-Escudero and Pujari 2009).

In *participatory design* (PD), people to be affected by the system are actively involved in system's design process; current, potential or future end-users co-operate with designers, developers and researchers through the innovation process (Schuler and Namioka 1993). The aim of participatory design is to ensure that the product is usable and meets end-users' needs. Participants work together at different stages of the development process from initial exploration and problem definition to evaluation of proposed solutions.

The ideological difference between user-centred design and participatory design is that user-centred design can be understood as *"designing for the user"* and participatory design as *"designing with the user"*. There is also overlap between these approaches (Sanders and Stappers 2008) and, for example, Dix, Finlay, Abowd and Beale (2003) state that design can only be effective if the users contribute to it.

User experience (UX) is defined as *"a person's perceptions and responses that result from the use or anticipated use of a product, system or service"* (ISO FDIS 9241-210 2009). User experience is influenced by both the user and the context of use. Usability is one of the things that affect user experience, not a synonym for it (Hassenzahl and Tractinsky 2006). UX comprises all of the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviour and accomplishments that occur before, during and after use. The aim of user-centred design can be summed up in most cases as maximising UX.

3.1.1 User involvement in design process

Co-design is a participatory development process where professional designers encourage and guide end-users to develop a product, service or organization in co-operation with them. The co-design process aims to ensure that the final result satisfies the end-user. Widely used and well established methods to involve end-users in the design process include focus groups, scenarios, early phase concept design and sketching (Morgan 1997, Carrol 2003, Greenbaum and Kyng 1992, Buxton 2007).

The *focus group* approach to co-design is a qualitative research method in which a small group of people of similar background participate in an interactive session led by a facilitator (Morgan 1997). During the session participants are asked about their attitudes and opinions about a product, service or concept. Participants are free to express their ideas and talk with other group members. The aim of a focus group is to find out people's perceptions, beliefs and expectations towards use of a product, service or concept.

Another commonly used method of user participation is the *focused interview.* The focused interview is a semi-structured method in which certain features, such as the interview focus, themes and some questions, are decided beforehand, but interviewees are encouraged to raise other aspects and viewpoints as well. Semi-structured interviews are often used when the objective is to explore the topic in depth and to gain thorough understanding of the answers provided and the interviewee's point of view, rather than making generalizations (Hirsjärvi and Hurme 2001, Fontana and Frey 2005). A focused interview can be either an individual interview or a focus group interview.

Such qualitative research methods are generally applicable when the research target is 'fuzzy' or unknown, and unexpected viewpoints may arise (Gephart 2004). Interviews and focus groups are effective approaches when dealing with complex responses and conflicting information and, because the researcher is able to ask clarifying questions, they enable in-depth understanding of the mindset of the respondent.

Ideas can be tested with users, for example, by using *scenarios* at different stages of the concept or product design process (Norman 1998, Maguire 2001). Scenarios can be used, for example, in surveys, focus groups or focused interviews to concretize new technologies and to activate discussion.

Thinking and drawing are simultaneous cognitive processes (Gydenryd 1998). *Sketching* is thus a highly effective means of accessing the thinking process (Buxton 2007, Suwa, Gero and Puercell 1998, Tohidi, Buxton, Baecker and Sellen 2006). Sketches in this context are simple, illustrative drawings, with no artistic abilities required. Sketching is an acknowledged co-design method for obtaining reflective user feedback through which participants create a visual explanation of the system of interest (Buxton 2007, Tohidi et al. 2006).

Co-creation in its original sense is a product development method where consumers actively co-operate with firms in order to create value through new forms of interaction (Prahalad and Ramaswamy 2000). The method has also been adopted in service design. Co-creation focuses on user experience; the user is able to personalize the way she or he uses the product or service (Jaworski and Kohli 2006). This interactive customer relationship transforms the economics of the organization and becomes part of its value chain. The terms co-design and co-creation are often used as synonyms. In our research, we use the term co-design in the more general sense of involving users in the design process, and co-creation in the specific sense of co-creation sessions where users are involved in creation as future customers.

User innovations tend to occur during the use of a product or service (Von Hippel 1986, Von Hippel 2005). According to von Hippel (1986, 2001) *lead users* play a key role in user innovations as they are conscious and ahead of trends.

Information digitalization affects many areas of society. In marketing, it has caused a paradigm change – a transition from products to *services*. According to Vargo and Lusch, goods are seen as distribution mechanisms for service provision, and the value of goods is based on value-in-use (Vargo, Lusch 2004) or value-in-context (Vargo, Lusch and Akaka 2010). Depending on the viewpoint, the transition has been from a *goods-dominant logic* (GDL) to a *service-dominant logic* (SDL) (Vargo and Lusch 2008) or *Nordic school logic*, aka *service logic* (SD)

(Grönroos 1978, Gummesson 1991). The Nordic School[16] sees service as a perspective of value creation (Edvardsson, Gustafsson and Roos 2005), and both customer and provider are considered necessary for value creation (Nenonen and Storbacka 2010). Nordic school representatives also consider that marketing strategies developed for services may also be applied to the marketing of goods, as goods marketing has an increasing amount of service elements (Grönroos 2006). Although there are some differences in how researchers view marketing strategies and how they formulate marketing logic, it is generally accepted that the role of services in the economy is increasing.

Compared to a traditional product-based economy, service innovation requires a greater degree of user participation, as well as new practices for realizing it (Menor, Tatikonda and Sampson 2002, Alam and Perry 2002, Kowalkowski 2010).

Transition from products to services has been especially strong in the software industry, where the SaaS (Software as a Service) paradigm is gaining ground. A *digital business ecosystem* is an interactive self-organizing business community acting in the environment that it creates through interaction within the community. Vargo and Lusch (2014) define *service ecosystem* as a relatively self-contained, self-adjusting system of resource-integrating actors that are connected by sharing institutional logics and mutual value creation through service exchange.

3.1.2 Technology adoption and acceptance

The general adoption of a new technology is influenced by a number of key factors. Firstly, personal characteristics affect individual adoption. People belong in different categories of the technology adoption lifecycle depending on how easily they adopt new technology (Bohlen and Beal 1957). Furthermore, the characteristics of the technology and use situation influence the adoption. Key factors influencing adoption include relative advantage compared to other technologies, compatibility and relevance, complexity or simplicity, triableness (how easily the user can test it) and observability (peers and social networks) (Rogers 2003, Compeau and Higgins 1995).

Besides usability, the assumed benefit and attitude towards use affect how users come to accept and use a technology. Other factors affecting the adoption and acceptance of an individual are: voluntariness of use, experience, output quality, demonstrable results, perceived ease of use and social acceptance (Davis 1989, Venkatesh and Davis 2000).

The rapid development of mobile technologies has changed user behaviour. For example, mobile barcode activity has increased remarkably and is still increasing (Frost & Sullivan 2012). The use of mobile applications has reached ‘the majority’ in the *technology acceptance model* (TAM) (Davis 1989).

---

[16] The Nordic school is a marketing school of thought that originally grew out of research into services marketing in Scandinavia and Finland; see e.g. (Grönroos and Gummesson 1985).

According to Kaasinen (2005) and Olsson, Lagerstam, Kärkkäinen and Väänänen-Vainio-Mattila (2011) the most important factors affecting intention of use and user acceptance of consumer-level digital services such as Internet, mobile and location-aware information services, are perceived value of the service, perceived ease of use and trust. The main obstacle to consumer-level mobile applications is often getting consumers to start using the service in the first place (Kaasinen 2005).

3.2 Overview of applied research methods and aims

A variety of web applications offering consumers the possibility for virtual home design are currently available. Typically, these applications allow the user to create a room space in 2D or 3D, or to choose from ready-made room models. Virtual home design services enable the user to select building products and decoration materials as well as household appliances and home electronics. Many applications provide virtual interior design with furniture and small decoration items, and some have augmented reality functionalities enabling the user to upload their own images and furnish them. AR functionalities are mainly limited to basic operations, such as adding and moving virtual items. (Oksman, Siltanen, Väätänen, Kulju and Kymäläinen 2011.)

Our aim was to determine how well these services meet consumers' needs and what kinds of expectations different user groups have, especially regarding AR services. Moreover, we wanted to blueprint an 'ideal future home design service'. In order to do this, we used several user-centred methods: co-design sessions, focus groups and focused interviews. Users were selected to represent three different user groups: *professional users*, *pro-users* and *ordinary users*, to enable the needs of different target user groups to be differentiated.

Interior design is very feminine activity, and thus it happened that all participants in studies 1 and 2, and most participants in study 5 were females, although the recruitment was open for both genders. However, they represent the average users as most of the interior design users are females.

The user groups consisted of "ordinary" people with a professional or personal interest in interior design and without any technical knowledge of AR or 3D modelling and no background in engineering. The consumers represented *ordinary users* i.e. average people in terms of technical knowledge and expertise in the service (Magnusson 2009). Pro-users had considerably better knowledge and understanding of the subject than ordinary users and therefore represented *lead users* as defined by von Hippel (2005, 1986), whereas professional users were seen as *critical users* of the service (Cassim and Dong 2003) due to their professional expertise on the subject.

Including both lead users and ordinary users in the development process is constructive (Alam 2006). In fact, including any alternative user group is beneficial; ordinary users, advanced users, critical users and even non-users can provide valuable contributions (Franke, von Hippel and Schreier 2006, Ainasoja et al. 2011, Heiskanen, Hyvönen, Repo and Saastamoinen 2007).

In addition to users, we involved service providers and other business actors with the intention to understand the service ecosystem and service concept. (Papers III, I and II)

Besides AR home design, we studied AR as part of a future *hybrid media concept*. By *hybrid media* we mean a system that connects print media and digital media. Our aim regarding the hybrid media field was to determine how augmented reality and other hybrid media solutions change the print media value chain and what kind of opportunities they offer for future print media. Especially we focused on AR advertising. In order to investigate human, business and technical aspects and to identify critical challenges, we interviewed 20 Finnish advertising and media business actors using focused interviews. (Paper IV)

Table 1. Research methods used for each interior design user group (green rows), and the hybrid media group (last, blue row).

Interior design service	Scenario-based survey	**Co-creation sessions**	**Focus groups**	**Focused interviews**
Ordinary users = consumers	X	**X**		
Pro-users (interior design bloggers and students)	X		**X**	
Professional users (professional interior designers)		**X**	**X**	**X**
Professional interest, ordinary users (interior design and lifestyle magazine editors)			**X**	
Business actors				**X**
Hybrid media				
Business actors				**X**

Table 1 clarifies how we studied each interest group and the research methods applied for to each group. All the methods support early concept design and user understanding (Maguire 2001). Studies concerning the interior design application area are marked green, and the study concerning hybrid media is marked blue (last row). Bolded items form the main focus. The results of a previously conducted scenario-based survey (see Paper III for details) were used in the planning of the interior design research. The survey is included in Table 1, although it falls outside the focus area of this work.

This work focuses on factors that make applications feasible in practice. Kymäläinen (2014), the co-author of Papers I and II, examined do-it-your-self design processes with a focus on smart do-it-yourself experiences and the human ecologies and characteristics of participants in the co-design phases of AR interior design.

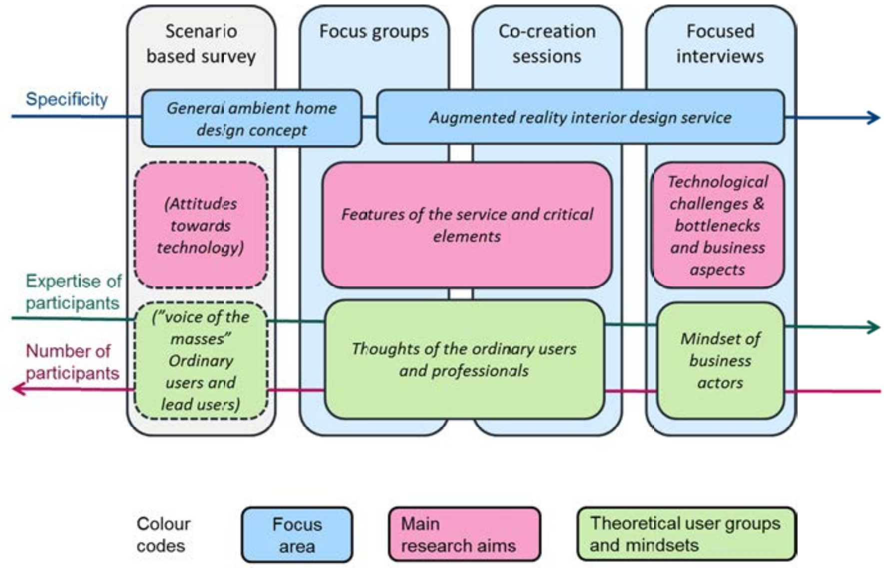


Figure 13. Overview of the applied research methods and research aims.

Figure 13 summaries the user-centric and participatory research methods and their research aims regarding home and interior design. The results of the scenario-based survey were used in the planning of the further research; it is therefore included in the table, although it is not part of this work. The research methods are presented in temporal order from left to right.

The focus area varies across the research methods, starting from the general ambient home design concept and narrowing towards AR interior design service. The focus areas of research are presented with darker blue boxes, in top row. The "speciality" of the focus area thus increases from left to right.

The research aim was to first determine attitudes towards the technology, then the features and critical elements of the service and, finally, the technical challenges and bottlenecks and business aspects. Main research aims are presented in pink boxes, in middle row.

In the different studies the theoretical user groups and mindsets vary from ordinary users (presenting the "voice of masses") and lead users, to professional users and the mindset of business actors. The expertise of the participants increases from left to right. The user groups and mindsets are presented with green boxes, in bottom row. The number of participants is large in the scenario-based survey and reduces in later studies. Thus, the number of participants increases from right to left.

The colours used for each research theme are explained below the image. The axes (speciality, expertise of participants and number of participants) are only indicative.

After sketching an *overall ambient home design concept*, we focused on one potential business model; *augmented reality interior design*. The actors involved in the value chain of the studied augmented reality interior design service are presented in Figure 14. The consumer can directly use the service, or a professional interior designer or a company may provide interior design service to the consumer. The consumer can also consult an interior design enthusiast. A furniture retailer utilizes a platform provided by a software company. Companies providing virtual interior design could have their own service and provide access to it to selected users.

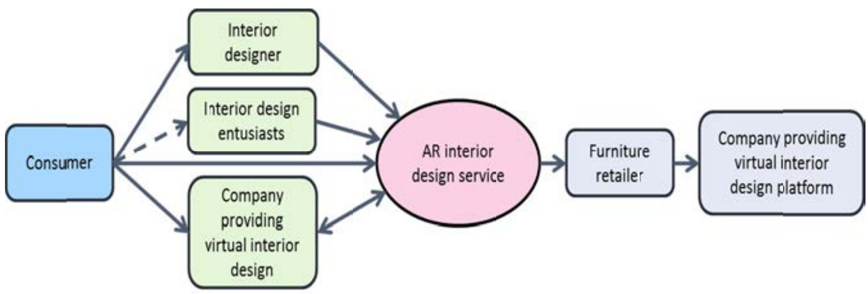


Figure 14. Value chain of potential users and service providers of the AR interior design service

Interior design enthusiasts (i.e. bloggers) participated in the survey and in the focus groups, consumers participated in the survey and in the co-creation sessions, interior designers participated in the co-creation sessions and focused interviews, and business actors, i.e. representatives of three companies, participated in the focused interviews.

3.3 Study 1: Co-designing the interior design service with focus groups

This section is based on Papers I and II. These studies aimed at understanding the needs and requirements of interior design *service providers* and creating *a service concept that exploits augmented reality, 3D models and user-generated content*.

This part of our study comprised two focus group sessions; one focusing on the AR functionalities and service ecosystem (4 participants) and the other on the service user interface (6 participants). We call these the *AR focus group* and the *UI focus group*. The focus group participants were selected from the respondents of the preliminary survey (see page 39). They thus had some personal or professional interest in the subject and were familiar with the background concept. The similarity of the participants within the theoretical framework of the focus group method was thus in this case the participants' interest in interior design. Because of their experience, the participants were seen as critical users (Cassim and Dong 2003) of the future service. In this section, we consider the AR focus group session, the implementation and results of which we describe next.

3.3.1 Implementation of Study 1

The primary aim of the focus groups was to sketch *'Novel web-based service concepts that exploit 3D and AR technologies, which can be used virtually for creating interior and renovation designs'*, with a focus on the *service ecosystem*.

Focus group participants – interior design bloggers, interior design students, and interior designers – would presumably use the sketched service to produce interior design plans for their customers or readers. In that sense, the participants were considered as *service providers*. On the other hand, their role in the sketch was defined simply as *designer* at the beginning of the session.

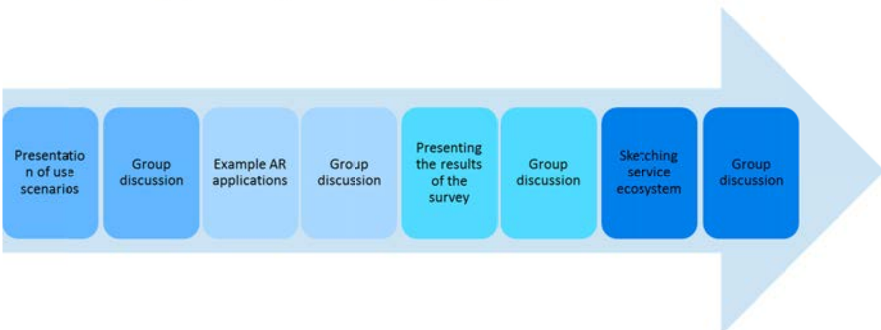


Figure 15. Course of the AR focus group session.

The AR focus group session consisted of four parts: presentation of use scenarios, presentation of example AR applications, presenting the results of the preliminary survey and sketching the service ecosystem in pairs. Each part was followed by a group discussion concerning that part (Figure 15).

The AR focus group had a researcher facilitating the session and four participants: three interior design bloggers, one of which was also an interior design student, and an AR expert. Participants were 27–49-year-old females.

At the beginning of the session, the facilitator presented four use scenarios for the imaginary future service (see Appendix A: AR use scenarios 1–4), and participants commented on how realistic they consider them.

Next, the facilitator presented three existing AR interior design applications using screen capture images for inspiration. These applications were previously benchmarked (Oksman et al. 2011) and thereby the presentation included a short description of features of each application and its benefits and similarities with the hypothetical future home design concept. The task of the participants was to consider the most important features of the future service considering their field of expertise and their work.

In the third part of the session the facilitator presented the results of the preliminary survey carried out previously (see page 39). This was followed by a short discussion.

The first three parts of the session served as an introduction to the most important phase; the *co-design session*, in which participants sketched the service eco-system for the future AR interior design service. During the co-design phase all previous material was accessible.

For the co-design session, the participants were divided into pairs. It was mutually decided that the participant's role in the sketching was as an ambiguous *designer*. In order to avoid blank paper syndrome, each pair positioned 'designer' in the middle of a poster sized paper. Thereafter, the pairs were assigned to produce around this a flow chart of the service ecosystem. They were to consider at least the following items:

- All necessary stakeholders and elements, i.e. products, services, technologies, etc.
- How all stakeholders and elements are connected to the ecosystem?
- Which are the most important stakeholders and elements (using a three-level scale)?

The participants had papers, pens, cardboards, and other sketching aids at hand. In addition, we provided them other inspiring materials (Figure 16) such as colour patterns, wall paper samples, images of furniture, etc., similar to the IDEO tech box (Kelley and Littman 2001).

Figure 16. Focus group session.

After the sketches were ready, each pair presented their sketch to the rest of the group for discussion. During the discussion participants improved their sketches based on the group feedback.

The IU focus group session differed only in the sketching task; their assignment was to sketch user interfaces for the service. User interfaces were analysed by the co-author and thus the results regarding user interfaces are omitted in this thesis.

3.3.2 Outcomes of Study 1

First of all, the participants provided valuable design information during the discussions regarding promising ways of utilizing AR technology in the service concept (Paper I).

Already in the first discussion, after familiarizing with the scenarios, the participants highlighted the importance of good usability. Later on, the interior design bloggers emphasized the need for the design tool to be user-friendly and simple to use. Good user experience is always important, in this case even more so; according to participants, it would be advantageous if using the service would feel like *"a leisure activity".*

The participants discussed the characteristics of the service while considering how they would like to use it themselves, and listed important features. They postulated that the tool must have accurately and authentically sized and proportioned furniture, rooms and apartments; otherwise it would be useless for them. It should be able to present the style and colour of virtual elements fairly well. The interior design enthusiasts stated that the tool should be able to create the 'atmosphere' that the design is aiming to achieve. Participants commented on the visual appearance, i.e. aesthetics, of the example AR interior design applications, stating that the virtual elements should appear natural and realistic, and the lighting and shadows authentic.

The starting point for interior design planning is usually existing furniture. Therefore, the group members considered the ability to manipulate existing furniture in the design to be more important than buying new furniture through the service. On the other hand, they speculated that providing such service is probably in the interest of nobody. It was therefore considered that if the tool is to focus exclusively on selling furniture, then all major furniture providers should have all of their products available through the system.

The participants considered it important that the service should allow the user to save the work and continue it from any point in the design process. Sharing designs through social media, as proposed in the presented scenarios, was considered a good supplementary feature. The idea of an interior design contest was considered interesting only if there is something to be gained from participation.

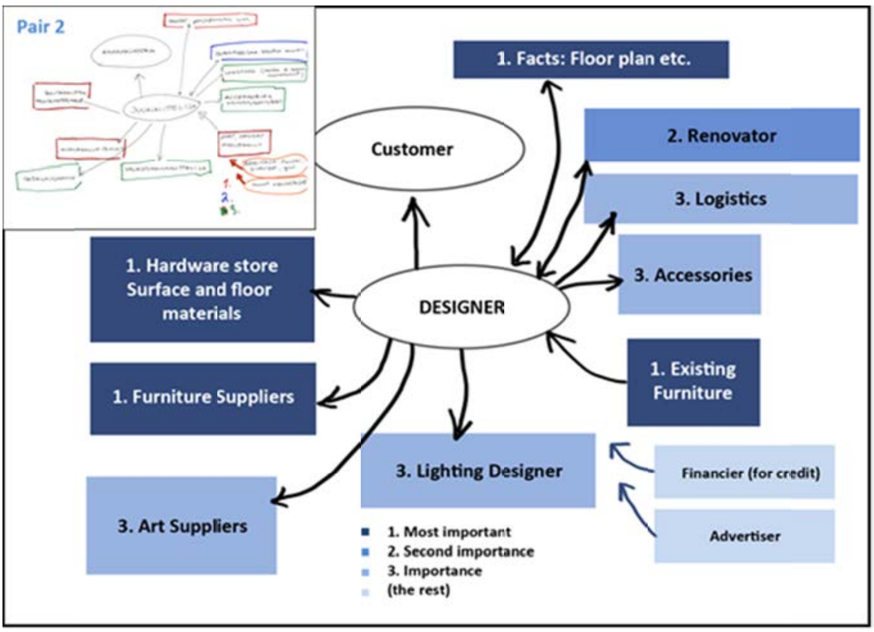


Figure 17. A sketch created in the AR focus group session.

Figure 17 illustrates one of the sketches created during the AR focus group session (see Paper II for more sketches). The figure shows the English transcription of the original sketch in Finnish (shown in the top left corner). The pair creating this sketch explained that the designer uses the service; therefore in the sketch designer represents the service.

A collection of product providers, actors and other items emerged in the sketches. All items were scored using the three-level scale used in the sketches. The most important items were: new furniture providers, interior decoration providers, owner/buyer of apartment, existing furniture, wall papers & paint providers, hardware stores and other interior designers or renovators.

However, there was inconsistency between the verbal explanations and sketches; participants, for example, emphasized the importance of existing furniture in the discussion, yet this did not receive full points. Therefore, the order of importance should be seen as indicative only.

All in all, the "Focus group user evaluations and co-design sessions provided adequately new information for further design and development of interactive interior design services that utilize AR technology" (Paper I).

3.4 Study 2: Co-creation sessions with consumers and interior designers

This subsection is based on Paper III.

The co-creation sessions focused on a concept defined as a fictitious web-based augmented reality interior design service that the user can operate on a laptop, PC or tablet, and which enables ordinary people to easily plan furnishing and decoration in the home environment.

3.4.1 Implementation of Study 2

We organized six co-creation sessions; five consumers participated in individual co-creation sessions, and the two interior designers participated in a joint session.

The sessions were carried out by same researcher and lasted 1–1.5 hours. The participants of the co-creation sessions were 30–50-year-old females.

In computer science, AR, VR, diminished reality, augmented virtuality, etc., are distinguished from each other (see page 22). To the layperson, however, the nuances of these definitions can be difficult to grasp. In the co-creation sessions, therefore, we defined the term *augmented reality* simply as *a system that combines real and virtual elements*.

The co-creation sessions consisted of three parts:

- **Introduction** with scenarios and a video: discussion of potential use cases of the technology, and first impressions
- **Experimenting** with an existing AR interior design service and reflection on it
- **Discussion:** personal opinions and preferences, and overall comments.

As the consumers were unfamiliar with the augmented reality concept, the consumer sessions were started with an introduction to AR in which the researcher briefly presented four scenarios (Scenarios 1–4 in Appendix A and Paper III) and a short video illustrating the use of an AR interior design service. Immediately after the introduction, first impressions and opinions were collected on how realistic the participants considered the presented scenarios. No introduction was needed for the interior designers, as they were already familiar with the concept of AR interior design.

The sessions were continued by experimenting with the AR interior design service in practice. Participants were instructed in advance to bring a few digital photos of their home to the session. Any participant who did not bring their own photos was provided with random images by the researcher, or, if the session took place in the participant's home, images were taken during the session. We then used a publicly available online interior design service to augment the images. The application was used as a means of activating discussion, emphasizing that the participant should not deliberate whether ideas are possible, but think creatively.

In order to allow participants to focus on generating ideas and on the general concept rather than on the particular application and its user, the researcher operated the application throughout the session. The participants expressed their ideas freely, with statements such as *"I'd like to remove this piece of furniture"* and *"I'd like to add here…"* If a participant came up with an idea that was not achievable with the application in question, the idea was discussed in detail. If the participant's idea was doable, the idea was executed while discussing it further.

During the experimental part of the session, the following themes were discussed: desired functionalities, potential or actual problems, and the naturalness of the real–virtual combination.

Each co-creation session ended with a discussion on the following themes: Would you use this kind of system when buying a new house? Would you use such a system to buy products from an online store? What are the most important features of such a system (when buying a new home or renovating/carrying out interior design)? Would you use this kind of system to share designs? What sorts of products could be trialled virtually? Any other comments?

3.4.2 Outcomes of Study 2

One of the key findings of the co-creation sessions was that the professional users and consumers had different needs and expectations regarding the AR interior design service. Their opinions regarding the importance of different attributes of the service therefore differed.

For professional interior designers that would use the service to produce interior design plans, accurate sizes and dimensions are highly important as the plan is used *"to show how the furniture fits in the physical space"*. The professional designers emphasized the role of colours and materials in interior design planning and the importance of the AR service being able to represent furniture in realistic lighting and realistic materials.

Consumers wanted to be able to search for items based on price, colour and size. As regards accuracy and rendering quality, the consumers preferred realistic augmentation over accuracy.

The consumers, as occasional users, considered ease of use important, and thus favoured limited features over a complicated user interface. In the consumers' view, the first-time use should be intuitive with no learning required. In contrast, the professional users wanted to be able to perform more demanding tasks, and thus preferred a system with more features even at the cost of ease of use. The professional users were also willing to invest time in learning to use the application and its numerous features in order to be able to use it to its full benefit.

The user groups, i.e. consumers and professionals, also shared a number of similar opinions. They considered interactions with existing furniture to be highly important; the service should enable existing furniture to be moved and removed virtually, and virtual furniture to be place behind existing furniture.

For both user groups, the studied AR service facilitates interior design testing and enables the user to carry out actions that would be otherwise impossible for them in the real world (e.g. moving heavy furniture and testing a new couch at home). These benefits are considered the prime reasons for using the AR service. In Study 1, the users also described "day dreaming" as a reason to use the service.

Interior design plans are rarely produced for empty rooms. Moreover, people normally have *"old furniture with sentimental value"* that they wish to retain. The lack of features enabling interaction with existing furniture was considered one of critical bottlenecks preventing real use of the AR service.

Another interesting discovery was that those consumers, who explored the service with images of their own home, were not only interested to explore more interior design ideas, but also came up with more ideas, compared to those who used images of a random room. This indicates that concretization of the concept using the user's own environment motivates the user, and also results in more concrete use scenarios. This finding is in line with the general concepts of human-centred design (Maguire 2001) and user innovations (von Hippel 1986, 2005).

3.5 Study 3: Focused interviews on AR interior design

Focused interviews were used in two studies in order to gain understanding of the business factors and business ecosystems influencing the acceptance of AR technology. The first study focused on AR interior design and the second study on the use of AR in hybrid media. The focused interview research method was chosen for its ability to elicit new viewpoints and due to the complexity of the service ecosystems. This subsection is based on Paper III.

3.5.1 Implementation of Study 3

The focused interviews were designed to gain understanding of the business factors influencing AR adoption as well as the mindset of professional users. A parallel objective was to investigate the importance of different features of the service from the business actors' viewpoint.

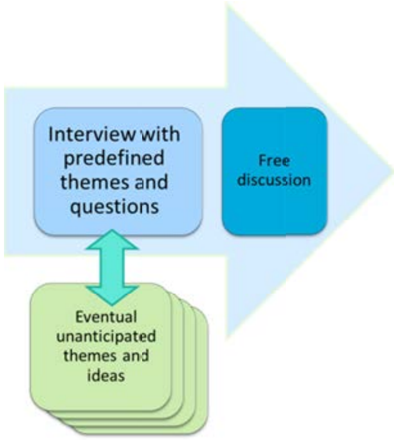


Figure 18. Format of the focused interviews on AR interior design.

Interviews were carried out as individual focused interviews, with the exception of two interior designers who were interviewed jointly. Three company representatives and three interior designers were interviewed (two of the latter in a joint interview) in a total of five interviews. All interviewees were part of the interior design service value chain (presented in Figure 14, page 40), and thus familiar with the augmented reality service concept. Therefore, no introduction was needed and the interviews started directly with prepared themes. Figure 18 depicts the format of the focused interviews on AR interior design.

The interviewees were either users of the service or service providers, or represented both roles, as depicted in Figure 19. Here, the professional interior designers use the service for producing interior design plans for their customers, while the software company providing a web-based AR interior design platform is a service provider. The furniture retailer uses the service that the software company provides, but provides the service further to consumers. In this sense, it is both a service provider and a user of the service. The company providing virtual and AR interior design has its own software solution, and thus can act as both a user and a service provider.

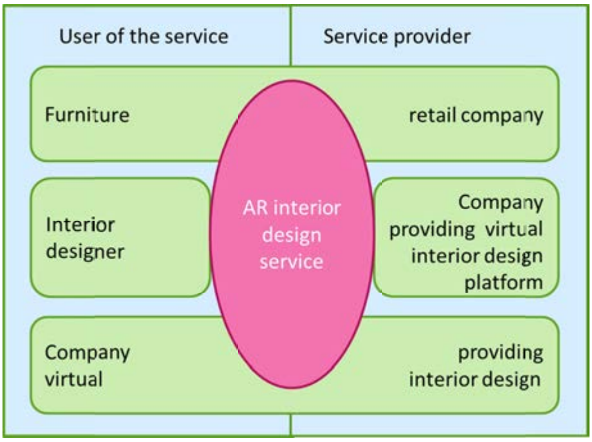


Figure 19. Interviewed actors representing both users and providers of AR interior design service.

The themes of the interviews were (where applicable to interviewee's business role):

- Desired features of the AR interior design service
- Target users and potential users
- Future of the service
- Bottlenecks and technical challenges
- User feedback
- Integration to other services
- Business prospects

Other themes were also discussed if they emerged.

3.5.2 Outcomes of Study 3

The service providers considered integration with other services, such as a web store, social media, real estate marketing, etc., an interesting possibility. In addition, the retailer, in particular, also considered other functionalities that support marketing and enable different campaigns, blogs, design competitions, etc. appealing.

The scenarios used in the consumer studies were not presented to the business actors, yet the business actors came up with very similar ideas spontaneously. The study thus validated the relevance of the consumer studies.

All interviewees agreed that the service should contain a large selection of furniture in order to allow creative solutions and not to limit interior design plans.

3.6 Study 4: Focused interviews on hybrid media

This section is based on Paper IV. In this study, we used focused interviews to examine the use of AR in hybrid media advertising.

3.6.1 Implementation of Study 4

Each interview started with a brief introduction to augmented reality and existing applications. The predefined themes were then discussed. Any new ideas emerging during the interview were discussed, after which the discussion was returned to the predefined themes. At the end, the participants were asked to share any thoughts that came to mind (Figure 20).

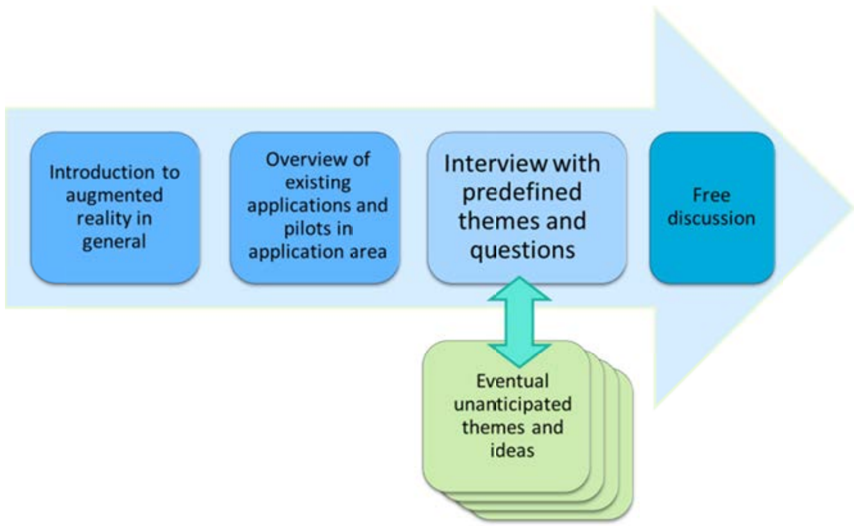


Figure 20. Format of the focused interviews on hybrid media.

Augmented reality advertisement means, in this context, a system where something in the printed matter triggers a virtual advertisement when using an AR viewer application on a mobile device. In this case an AR tool is required for creating the AR advertisement, i.e. connecting AR content to the printed matter, etc. In Paper IV, we described the components of the AR advertisement as presented in Figure 21.

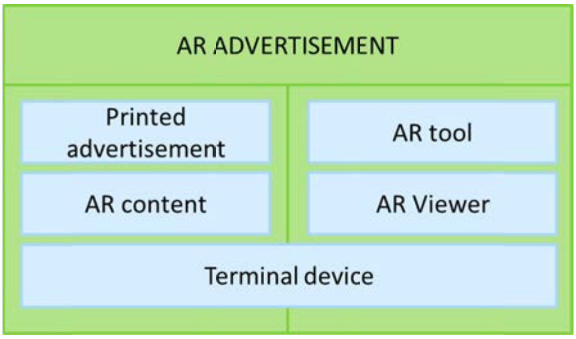


Figure 21. Components of AR advertisement.

We interviewed 20 advertising and media actors from 11 companies based in Finland. The companies had different roles in the print media value chain, from brand owners to printing houses, and the interviewees had varying expertise from marketing to social media (Table 2).

Each interview started with a brief introduction to augmented reality and hybrid media applications. The following themes were then discussed with the interviewees:

- **Roadmap of print media and the role of AR in it:** What is the role of print media and print advertising today and how it will change in the next five years? What opportunities and challenges will AR bring to print media?

- **Target groups for AR applications:** What print products will AR applications suit best? What target groups will be reached?

- **The new hybrid media value chain:** How will the print media value chain change as AR applications become an integral part of print advertising? Who will take the leading role in AR production and who will make business out of it?

We ended each interview with free discussion.

Table 2. Participants of the focused interviews on hybrid media. Participants of same company are in the same row in the 'Expertise of participants' and 'Number of participants' columns.

Interviewed companies	Company's position in the value chain	Expertise of participants	Number of participants
Company 1	Brand owner	Marketing	3
Company 2	Brand owner	Product	3
Company 3	Advertising	Digital content	1
Company 4	Advertising	Digital content	1
Company 5	Media agency	Media planner	1
Company 6	Publisher	On-line	2
Company 7	Publisher	Social media	2
Company 8	Publisher	Production	1
Company 9	Publisher	Marketing	1
Company 10	Printing	Sales and Digital printing	1 2
Company 11	Printing	Direct mail	2

3.6.2 Outcomes of Study 4

Each participant viewed the role of the company they represented important in the future hybrid media value chain – and stronger than the other interviewees considered it to be. Almost all participants thus seemed to overrate their own role. Nonetheless, all participants shared a similar vision regarding the components of the value chain.

In this study we interviewed only business actors, the consumers were not involved in this study. However, the interviewed business actors study their consumers constantly, and thus their opinions take into account consumers' way of thinking.

An important outcome of the interviews was an expressed need for a comprehensive system to enable the use of augmented reality advertising. More specifically, instead of separate applications and one-time campaigns, the system should be such that it can be used continuously for diverse purposes and with minimal effort.

Firstly, this means that *authoring* must be separated from end user applications and that the AR component should be part of a wider hybrid media concept. In the AR context, authoring means defining the functionalities and relationships of virtual objects at the conceptual level: which object is augmented where, and what kinds of interactions are activated and how, etc. Drawing these elements together, we can describe the components of the hybrid media concept, of which AR advertisement is one potential application, as shown in Figure 22 (cf. components of AR advertisement presented in Figure 21).

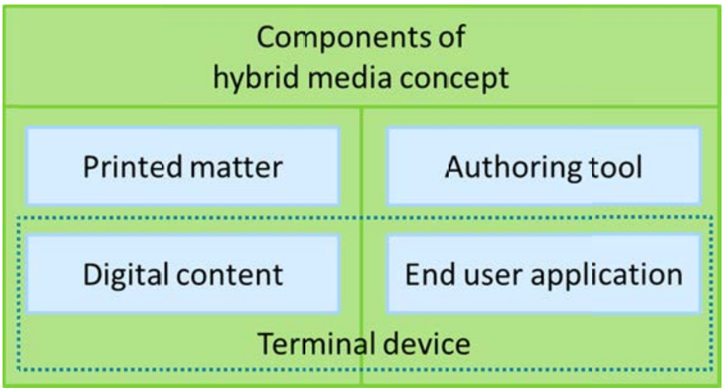


Figure 22. Components of the hybrid media concept.

The hybrid media framework is a whole system that defines how contents are managed and edited, how digital information is linked to printed matter and how the application is distributed, etc. In this framework, the terminal device influences the possible options; tablets and mobile phones have different graphics support, for example. Otherwise, the system consists of four essential parts: printed matter, digital content, authoring tool, and end user application. The target terminal device affects choices concerning the digital content and the end user application.

In practice, it is convenient to use a vision-based system to activate the digital content; the mobile application detects the printed content with the camera, and reacts to it. Besides augmentations, the hybrid media application may launch a video, audio stream, or any other type of digital information.

In the case of an AR advertisement, the end user application is first used to scan the printed matter for digital content and then to show the augmentations. The printed matter (e.g. a printed advertisement) activates the AR component when it is detected by a mobile device. The authoring tool is used to define which printed matter triggers which augmentation and the features of the augmentation (e.g. animation paths and interactions).

The interviewees considered teenagers and active young people as early adopters of this kind of technology, and thus a potential target group of the service. Another potential target group is technology-oriented people interested in the application area or field of activity that the system is used for.

Adoption of the hybrid media concept in print media may alter the value chain and the roles of actors. Alternatively, there is room for a potential new actor providing the hybrid media framework (Figure 23).

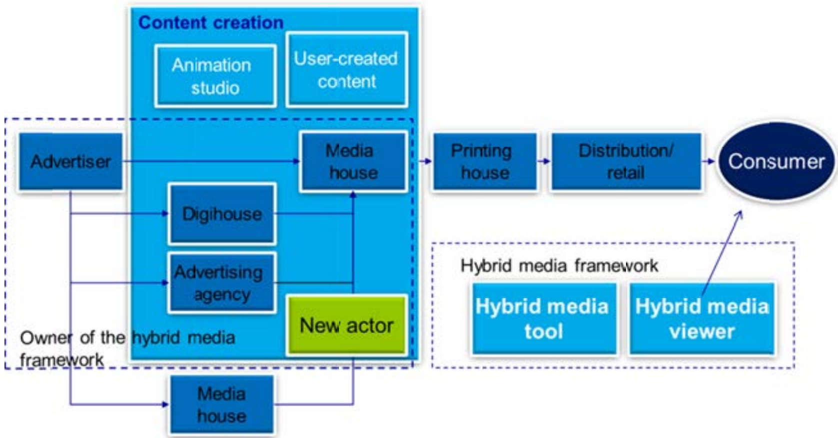


Figure 23. Value chain of a hybrid media solution for printed matter.

At the high end of the value chain is the advertiser (e.g. brand owner), and at the other end is the consumer. The distributor, e.g. retailer, is towards the lower end of the value chain. The role of distributor may change when distribution transfers from the physical retail shop to the digital market place. The role of the traditional printing house is minor, being essentially limited to printing what the customer wants.

A pure content creator, such as an animation studio, is in subcontractor role in providing content for hybrid media. Depending on the use case, user-created content may bring a degree of added value to the service, although it is not part of the actual value chain.

The role of the other actors is interesting; they might serve as the owners of the hybrid media framework. There is also space for a new actor to manage the framework.

The importance of ease-of-use was raised in all discussions. The system should be easy and intuitive to use from the start, both for the user and the provider.

All interviewees considered that hybrid media will be an essential part of future print media. A few reasons were given for this. To begin with, print media is losing its share of advertising and readers to digital media. The print media sector therefore needs to linkage with digital media to survive. Another important aspect is that linking print media with digital data transmission enables the collection of customer information – which is valuable currency in advertising.

With traditional print media, access to customer information is extremely limited. For instance, the effect of advertising campaigns can only be observed at a general level. With digital connection, however, the framework owner can collect considerably more information. When the user reads a printed publication (e.g. a magazine) with a mobile phone and launches additional information, the system knows when, and possibly also where, the user is and which of the several advertisements of the campaign the user is viewing. With registered users it is also possible to collect more background data. Moreover, the system enables direct linking from printed advertisement to web store, thus lowering the purchasing threshold. This naturally appeals to advertisers.

3.7 Study 5: Innovation workshop on AR real estate marketing

To complement our previous studies on ambient home design, we held an *innovation workshop* with three themes. The results concerning two of the themes, *Augmented reality in real estate marketing* and *AR in interior design,* were documented in the AdFeed[17] project deliverable (Siltanen, Seisto, Mensonen and Wulff 2011) and are described here with permission of the respective project partners. This subsection is based on that work.

The third workshop theme, *presentation of a device for measuring true colours and potential use cases for it*, is outside the scope of this work and omitted from the present analysis.

The augmented reality themes of the innovation workshop can be considered as a focus group session.

The objective of this study was *to find out how AR could be used in real estate marketing and how consumers perceive the concept of using additional virtual and/or augmented reality images of apartments in real estate marketing*.

The study also aimed to validate previous results regarding important features of an AR interior design service with a new group of users. In addition, we were interested in any new aspects arising from the real estate marketing business perspective.

---

[17] Adfeed was part of the Next Media programme of DIGILE (former TIVIT).

3.7.1 Implementation of Study 5

The main focus group of this study was journalists working in interior design or lifestyle magazines – ordinary people with a professional interest in interior design and homing[18]. A total of seven participants were included in this focus group session.

The session started with an introduction to augmented reality, including brief illustrations of AR use in real estate marketing and interior design (see Appendix B). After the introduction, participants were invited to ask questions. They were then divided into two groups for group discussions. Each group first discussed one of the themes together with a researcher, and then switched places to discuss the other theme with the other researcher (Figure 24).

The introduction illustrated the buyer's and seller's viewpoints regarding the use of AR in real estate marketing, in addition to the interior decorator's perspective on AR interior design.

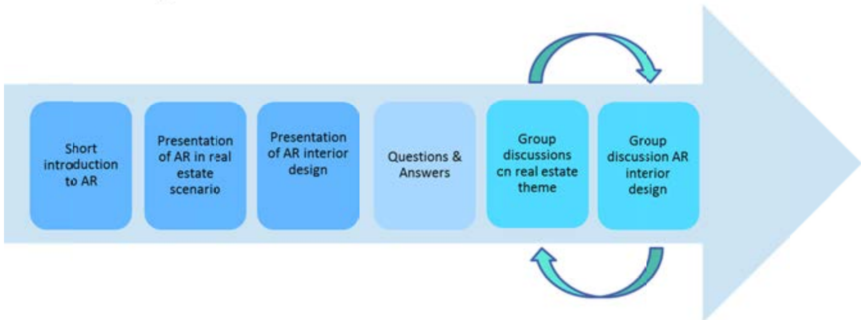


Figure 24. Focus group work flow in the innovation workshop.

In the group discussions, the participants had illustrations of use cases available at hand, and the researcher leading the group presented activating questions to the group. The discussions were recorded for later analysis. The illustrations and questions were:

Real estate marketing:

Illustrations of VR/AR features, as shown in Figure 25.
Questions to start the discussion:

---

[18] *'Homing'* is a trend that can be described as enjoying life at home, doing and making things yourself. This popular life-style trend includes activities as knitting, home decorating, interior design and baking.

- Who benefits from using virtual and modified images?
- What do people expect from this kind of service?
- Who would edit the images? The seller? The real estate agent? Interior designer? Buyer? Furniture manufacturer? Furniture retailer?

Interior design:

Illustrated examples: moving a piano virtually, virtually converting a TV room into a dining room, virtually testing a new couch, and visualizing a 2D interior design plan (see Appendix B).

Questions to start the discussion:

- What do people expect from this kind of service?
- What functionalities?
- What kind of user interface?

The group discussions were audio-recorded and transcribed to enable analysis of the results for both themes from both groups.

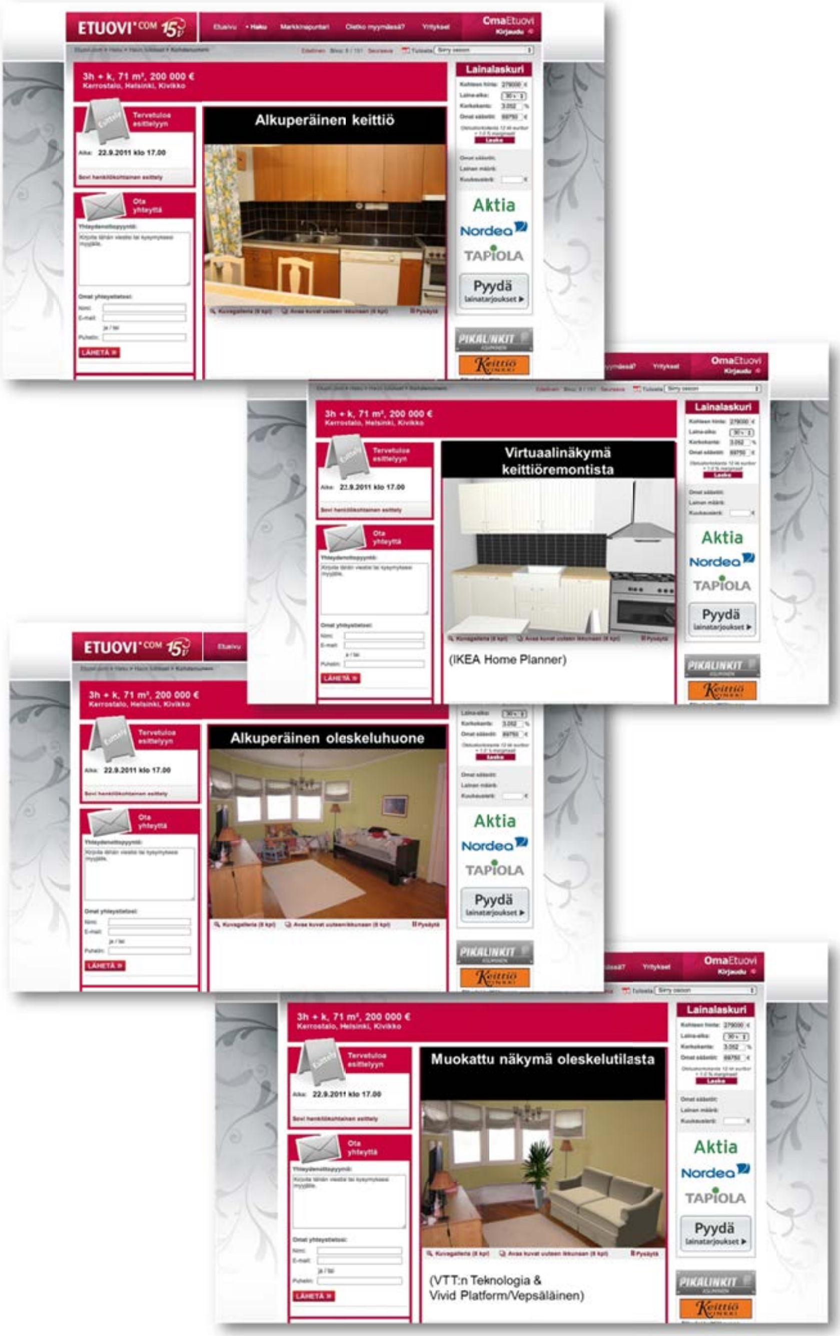


Figure 25. Example of VR/AR real estate marketing. From top: original kitchen, VR kitchen renovation; original living room, AR living room.

3.7.2 Outcomes of Study 5

All participants shared the opinion that AR and VR images bring added value to real estate marketing.

In the concept illustrations, the nature of all images was clearly marked. The user was always aware of whether an image was original, virtual, or manipulated with AR technology (Figure 25). No comments were presented concerning ethical issues or the acceptability of AR/VR modifications. Nobody expressed concern about misleading the customer or any other concerns about AR/VR modification.

Participants considered that the service should have different vendors in the portal: kitchen and bathroom fixtures, ceramic tile and furniture vendors, etc., and viewed it as important that several vendors from each branch are represented.

In the participants' view, the AR/VR interior design could either be a service provided by real estate agency, or a web service provided by a furniture vendor. Furthermore, although the service does not need to be free of charge for consumer, it could also be funded by advertising.

Important features would be the ability to: illustrate furniture placement from a 360° perspective; virtually remove existing furniture from images; and use own existing furniture in AR interior design. Participants also wished to see an avatar in the images to get better idea of scale.

Other key functionalities for such a software/service mentioned were the ability to measure real dimensions and to order custom-made furniture to fit real dimensions. The system should also have *"this [item] does not fit here"* type warnings.

Participants also considered that AR interior design would allow people to dream and make designs just for fun, rather like a *"Habbo Hotel*[19] *for adults".*

Other future features of AR interior design mentioned by the participants included: realistic lighting models to aid lighting design, virtual curtains, and suggestions for suitable furniture for a given space or the style.

In addition to interior design, the participants also envisaged a similar service for garden and terrace design. Such a system could visualize sunlight at different times of the day and year, as well as plants growing and blooming over time.

In summary, the focus group session served our purpose well; we determined users' attitudes towards the AR/VR interior design service concept, and identified how users would like to use such a service.

In this study we concentrated on a web-based service and its functionalities, and superficially discussed the possibility to use AR application on-site for real estate marketing. However, an interior design application could be used for visualising different interior design plans on-site in real estate marketing as well.

---

[19] Habbo Hotel virtual world: https://www.habbo.com/

4. Developing AR applications towards real use

A substantial finding of the previous chapter was that user experience is improved if the user is able to interact with the system in a way that feels natural to them. The user interface thus plays a significant role in user experience – but is by no means the only noteworthy aspect. Other important factors affecting user satisfaction relate to the usefulness of the system: how well the user can accomplish something with it, and how useful it is to the user.

In this chapter, we discuss our work on developing augmented reality applications towards wide consumer-level use. First we discuss user experience in augmented reality applications with a focus on assembly-type tasks, and then we focus on our specific interest area, augmented reality interior design. Our work especially takes into account user experience and usefulness as described above.

4.1 Improving UX in AR assembly tasks

AR has proven to be useful in assembly type areas i.e. in assembly, maintenance and repair (Siltanen 2012, Henderson and Feiner 2011a, Henderson and Feiner 2009, Bimber and Raskar 2005). The development of augmented reality field really took off after Caudell and Mizell (1992) demonstrated assembling aircraft electronics with the help of AR.

This section, based on Paper V, describes our work on multimodal user interface for augmented assembly with the aim of improving user experience. Several other research papers have also been presented by the author regarding the advancement of AR in assembly–type tasks (Sääski et al. 2007, Salonen et al. 2007, Sääski et al. 2008, Azpiazu et al. 2011) and natural user interfaces (Honkamaa et al. 2007, Ailisto et al. 2007, Siltanen et al. 2008).

We start the discussion on the use of AR in assembly tasks, and then turn the focus towards multimodality and user experience.

4.1.1 Augmented assembly benefits for manufacturing industry

The transition to service-dominant logic (see e.g. Vargo and Lusch 2008) has transformed product manufacturing from the production of fixed products to a growing number of product variants and customized products. Manufacturers often provide a service where the customer can select certain product features and production is realized on demand (Salvador, Chandrasekaran and Sohail 2014), as was the case in our tractor manufacturer study (Sääski et al. 2007).

Customization of products increases the complexity of the assembly task, increases the variety of components (Hu et al. 2011) and causes long assembly sequences, as also noted in our previous work (Sääski et al. 2007, Salonen et al. 2007). This means shorter life-cycles, smaller production lots, and accelerated time-to-market, which in turn increase demands on production equipment and production performance resulting in higher assembly costs (Hu et al. 2011, Chryssolouris 2006).

The manufacturing industry needs innovative approaches and technologies to meet the challenges of the current market economy (Hu et al. 2011, He and Lai 2012, Chryssolouris, Papakostas and Mavrikios 2008). Improvements in the assembly process can significantly reduce assembly costs and a product's time to market (Leu et al. 2013).

Augmented reality can combine human intelligence and skills with the memory capacity of a computer and thus make assembly more effective and less error-prone (Sääski et al. 2007, Novak-Marcincin, Barna, Janak and Novakova-Marcincinova 2013). This, in turn, lowers assembly costs thereby boosting the competitiveness of manufacturing companies. The same holds true for other similar tasks, such as maintenance and repair, where a clear advantage can be gained from supporting human skills and intelligence with the memory and processing capacity of a computer system.

The motivation to develop augmented reality systems to support assembly tasks is clear. In Paper V, we studied user interactions with such a system and, especially, how different modalities can be utilized in the user interface to increase UX. This is examined in the following section.

4.1.2 Multimodal user interface

In Paper V, we simulated real assembly work using a portable 3D block puzzle. The assembly task was to assemble the puzzle. We used a head-mounted display (HMD) setup consisting of a camera and lightweight video display, both attached to safety glasses worn by the assembler (Figure 26). (Sääski et al. 2007 and Paper V.)

Figure 26. Setup of the assembly demonstration.

In the assembly setup, the user follows the augmented instructions on the display to manually position the required parts in the right place and the right order. The parts fit in only if assembled correctly and in the right order. The task was designed to closely mimic a real manual assembly situation, using real objects and an authentic AR device. No tools were needed, however. This made the task quick to perform and to repeat, which suited our development and testing purposes and allowed us to easily examine different user interface modalities.

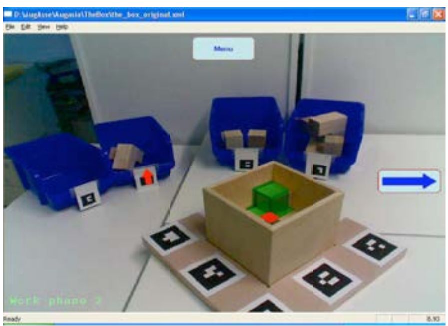


Figure 27. User's view of the system.

In assembly tasks non-photorealistic rendering (NPR) is preferred; the instructions are intended to grab the user's attention. Thus, we used bright colours for the augmentations in our demonstration (Figure 27).

Assembly is a hands-busy eyes-busy task thus the use of a tactile input, such as a keyboard, is both unnatural and inefficient. We therefore investigated the use of speech and gesture controls as more natural modes of system command and control (Bolt 1980). An adaptive user interface brings together the concepts of universal usability (Vanderheiden 2002). However, adaptive multimodal user interface research typically concerns the adaptation of content rather (David Endler, Barbosa and Filho 2011) than the adaptation of user interaction modalities as in our work. The modalities studied in our multimodal demonstration are presented in Figure 28.

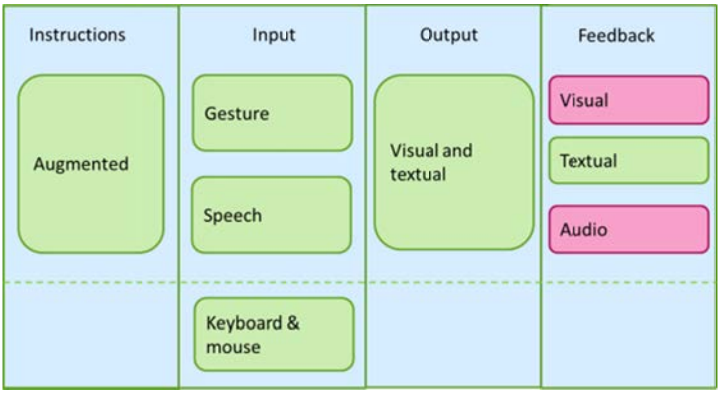


Figure 28. Modalities used in the multimodal demonstration. Users preferred visual and audio feedback.

The "gesture control" was actually a *gesture controlled virtual menu* user interface, meaning that the virtual menus were operated by selecting them by hand (see Figure 29). The system used hand detection based colour histogram back-projection (Swain and Ballard 1991).

Speech recognition was realized using the external *automatic speech recognition* (ASR) software Sonic speech recognizer in its client-server mode (Pellom 2001, Pellom and Hacioglu 2003). It was calibrated to identify simple commands such as 'next', 'previous', 'next phase', 'previous phase', etc. The system architecture allowed easily changing of the various ASR parameters and fine tuning of the recognition process.

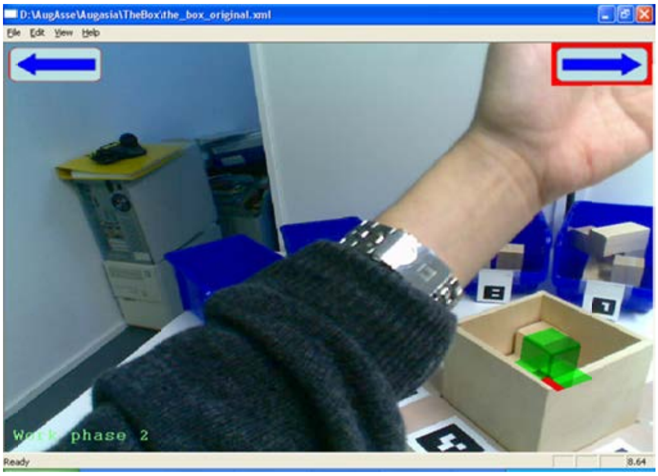


Figure 29. Virtual menus in action.

The system supported calibration of both speech recognition and hand recognition for the current user. The system architecture also allowed the addition of more modalities if needed.

We used a small test group to obtain indicative results for further development of a real assembly task of a tractor accessory's power unit (Sääski et al. 2007). Five novice users evaluated the system (two females, three males). Two of them had no previous experience of AR or HMDs, one had used a HMD before, and two were familiar with similar systems.

User evaluations consisted of three tests: single modality with speech recognition, single modality with gesture control and, adaptive multimodality with both speech and gesture control. The order of the single modalities was random, but the multimodal set up was always tested last. A control group used printed illustrated instructions.

It should be noted that industrial assembly takes place typically in a factory, i.e., closed environment. User attitudes towards speech and gesture user interfaces would likely be quite different for applications that are used in public spaces in view of other people.

4.1.3 Research outcomes concerning the multimodal user interface

Valuable feedback was obtained for developing an actual factory user interface.

The speech recognition and gesture recognition functions failed on occasion; we kept track of all failures in order to analyse their influence on mode preferences. The result was, as expected, clear; in the multimodality test the users preferred the modality that performed better in the first two tests.

The augmented instructions were explicit; no mistakes were made during the assembly. With the augmented instructions the users were able to turn the puzzle around and view it from any viewpoint they wished. In contrast, the paper instructions caused confusion as the illustrations were given from only one viewpoint and the users were not always certain of the required piece or position.

The test users gave valuable insights concerning the system. First of all, feedback from the tested set up was stated to be insufficient, with users emphasizing the importance of system feedback to the user experience. The users suggested a number of feedback improvements. Assembly type instructions require eye-catching augmentations as the aim is to get the user to focus on the right thing. The same holds true to some extent for menu items. In our test the position of the virtual menu was not optimal, and some graphics and texts were too small and thus unnoticeable.

The system repeatedly animated the assembly instruction for each piece until the user moved to the next step. One user suggested the possibility of freezing the animation to allow the user to compare the piece in hand with the piece shown in the animation – a useful feature for a real assembly task.

A somewhat obvious finding is that the system should support the task it is used for. While this may seem trivial in principle, it is not necessarily so obvious how best to support the task in practice. In assembly-type task, this means for example clear, eye-catching augmentations.

Another important result was that all users preferred multimodality over single modality. User experience is improved if the user is able to interact with the system in the way that they want. Use of a multimodal user interface is one way to support this. This is in line with the general aims of user-centred design (page 33).

The results were similar to other research results in the field. For example, Irawati, Green, Billinghurst, Dünser and Ko (2006) studied multimodal user interface using speech and gestures using a specific handheld paddle, and also noted the importance of feedback from the system to the user. Furthermore, their research shows that users prefer multimodality, and that multimodality can improve the efficiency of user interaction. Multimodality has also been proven to enhance learning, especially for students who learn through kinaesthetic, visual, and other non-text-based methods (Billinghurst and Dünser 2012).

The head-mounted video display used in the study proved suitable for this purpose. The display was light-weight and the image quality was good. The display was convenient to wear, being attached to normal safety glasses as would be worn by an assembler in a real factory environment. The display was positioned to the side of the assembler’s line of view, enabling the user to glimpse the instructions when needed, while allowing a direct view of the environment. In our practical experience, this type of HMD provides optimal support for assembly tasks (Siltanen 2012: 142–143).

The devices used in the experiments are no longer on the market. However, a number of new devices have since been released. The launch of see-through eyewear designed for AR such as Microsoft HoloLens (see Figure 56, page 102) on the market is likely to increase the number of consumer AR applications. Moreover, better speech recognition systems are now available, also for mobile devices (David et al. 2011).

One fundamental challenge emerged in all of our experiments with assembly type instructions; the system's ability to verify after each step whether the task has been accomplished correctly. Until recently, it has always been the user's responsibility to check that the right task has been carried out correctly and to then instruct the system to move forward. However, by combining the latest depth-cameras and computer vision into the AR system, it is possible to verify accomplished steps and notice any assembly errors automatically (Bui Minh et al. 2014, Kahn, Bockholt, Kuijper and Fellner 2013).

Another key finding is that the user should be in control of the system; the user should be aware of the state of the system (e.g. which task it is on) in order to feel comfortable when using the application. Too much automation may cause the user to lose track of what is happening and why.

4.2 Developing augmented reality for interior design

Ordinary people – i.e. people with no engineering or technical background – often have problems understanding the relations between 2D technical drawings and 3D reality (Mohler 2001), and even professionals can sometimes find this challenging (Fiorentino, Radkowski, Uva and Monno 2012). According to interior designers this is also true for interior design plans and 3D spaces; customers have problems understanding what the plan means with respect to an actual room (Paper III). Use of 3D graphics and animations increases a design's intuitiveness and aids human visual perception (Brath, Peters and Senior 2005, Spence 1990, Irani and Ware 2003). Thus, augmented reality can help people understand interior design plans better (Figure 30).

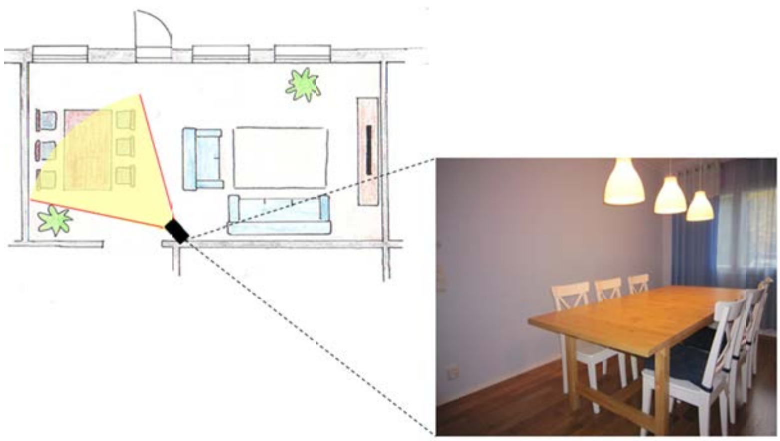


Figure 30. People can have difficulty understanding what interior design plans mean in reality. A concept image of AR interior design.

Another important aspect raised by professional interior designers and interior design semi-professionals in the present study is that the interior design process often starts with existing furniture. In addition, the colours and the "feeling of the space" are also important. (Papers III, I and II.) It therefore makes sense to combine new components with the existing environment, i.e. to use augmented reality.

Moreover, furniture retailers see an opportunity to increase sales through AR interior design services (Paper III). Real estate marketing can also benefit from AR interior design services (Siltanen et al. 2011) and interior designers and bloggers see an opportunity to advertise their work through such services (Paper I, Paper II).

Based on these findings, we have a clear motivation to develop augmented reality solutions for interior design.

4.2.1 AR development for interior design

Interior design has the following special characteristics compared to other AR application areas: users prefer still images to video (Paper VI, Saraspää 2014), the visual quality of the augmentation must be realistic (cf. assembly tasks where NPR is preferred, see page 62), and real dimensions are essential (cf. AR games) (Papers III, I and II).

Next, we will discuss the development of the AR interior design application described in Paper VI, on which this subsection is based.

In consumer applications the assumption is that the operator is an 'ordinary user', i.e. has no engineering background (Magnusson 2009), and thus the system must be easy to start using and its further use should be self-evident. In order to obtain an accurate scale and reasonable coordinates in a user-friendly way, we used marker-based tracking, whereby the user simply places a printed marker on the floor and then starts adding virtual furniture.

For marker detection we used ARToolkit with some modifications and additional features that we created for this purpose. These features were later implemented in ALVAR. One of these features that we created, and later improved, is *marker hiding* (Siltanen 2006, 2012, Korkalo, Aittala and Siltanen 2010). The use of markers in the augmented image can be distracting to the viewer, especially in interior design where visual appearance is paramount. However, their use is justified by their simplicity of use and the fact that they enable the use of correct scales. Marker hiding resolves this contradiction by removing the marker virtually from the final image.

A hybrid method can use markers for initialization (i.e. to get the correct scale and to align the coordinate system with the floor) and thereafter rely on feature-based or inertial tracking (Su, Kang and Tang 2008, Feng Zhou, Duh and Billinghurst 2008). In markerless tracking methods, the scale must be initialized one way or other. This usually requires some amount of expertise, making it inapplicable for consumer applications, but feasible for professional applications. As noted earlier, professional interior designers are willing to invest learning effort in return for superior functionality (see page 47).

Figure 31. Augmentation without adaptation (top) and with adaption under two different illumination conditions (below).

As discussed in Chapter 3, lighting and shadows create "the feeling of the space", and make the augmentation realistic. According to the professional users, these are important features of interior design (see page 67, Papers I, II and III). We implemented *adjustable lighting* with *soft shadows* (Gibson, Cook and Hubbold 2003) in our AR system. The user was able to adjust the characteristics and intensity of the ambient light as well as add and move virtual spotlights. This enabled the virtual light to be matched with the real light (Figure 31) – a feature greatly valued by the users (see e.g. pages 44, 47 and 59).

The philosophy behind the work was that the *consumers can test furniture virtually in their own living room.* Thus, the user was able to upload to the system any digital images (i.e. all sizes and common formats) taken with an ordinary digital camera – without needing to resize or change the image format. In addition, furniture was added dynamically as needed.

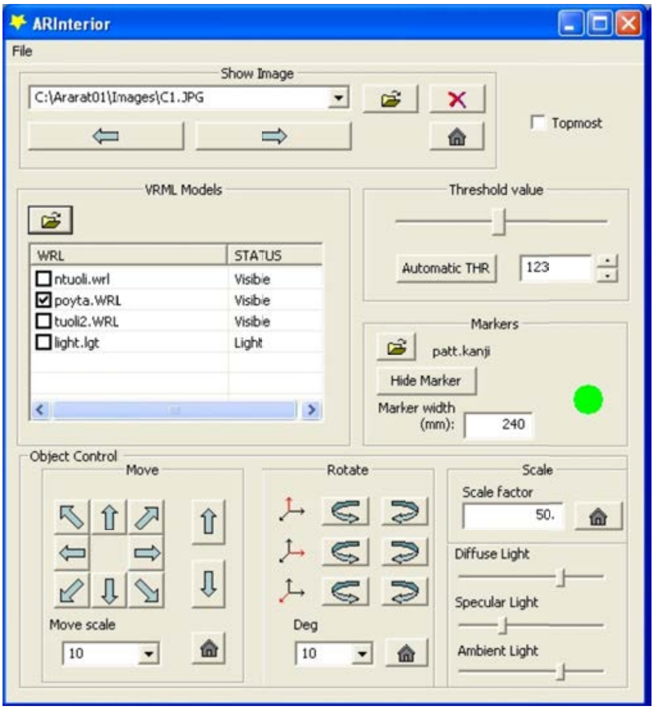


Figure 32. The user interface of AR interior design application.

The user interface was a ‘developer version’ with more options than a real consumer application would have (Figure 32). However, the interface allowed the user to select their preferred mode of interacting with the system, in accordance with user-centred design principles (see page 33). For instance, the user could move objects with a mouse or with buttons in the interface. We did not carry out large scale user test; however this flexibility was appreciated by the occasional test users. The user was also able to save interior design projects and continue the work later – another feature highly appreciated by the users (see page 44).

One of the important outcomes of Paper VI was a list of important features and challenges for future development. Building on the work described in Paper VI, we have further developed the AR technology to also support interior design in several other projects, such as AR-Sisustus[20], MMR[21], ADFeed[22] and CloudSW[23]. In

[20] Tekes TILA programme project **AR-sisustus**
[21] Tekes ICT-SHOK project **Mobile Mixed Reality** (**MMR**)
[22] Tivit Next media programme project **AdFeed**
[23] Digile Cloud Software programme, Business case 3D reconstruction/Vivid Works (**CloudSW**)

these projects we have solved all of the challenges identified in Paper VI. The current implementation uses the ALVAR library (Appendix C), which has accurate tracking and a range of integrated features.

4.2.2 Diminished reality

Earlier we identified some bottlenecks against using virtual interior design applications for serious purposes. Above all were the inability to handle overlapping with existing furniture and the inability to remove existing furniture virtually (see page 47, Papers III, I and II). Solving these problems would presumably advance AR towards wide use in interior design. We have consequently developed the *diminished reality* solutions described in Paper VII to overcome these problems. This section is based on Paper VII.

Although our focus is still-image based interior design application, such application can easily be extended to a real-time AR application by adding a tracking module as discussed earlier. In order to provide widely useful solution for a variety of AR applications, the development for diminished reality functionality aims for real-time methods.

Figure 33. Augmentation appears flawed if virtual elements are augmented over objects that should be foregrounded. If the foreground object is unimportant the problem can be solved by using diminished reality (Siltanen 2012).

Figure 33 and Figure 34 illustrate practical situations where diminished reality solves the overlapping problem and enhances the visual credibility of the augmentation.

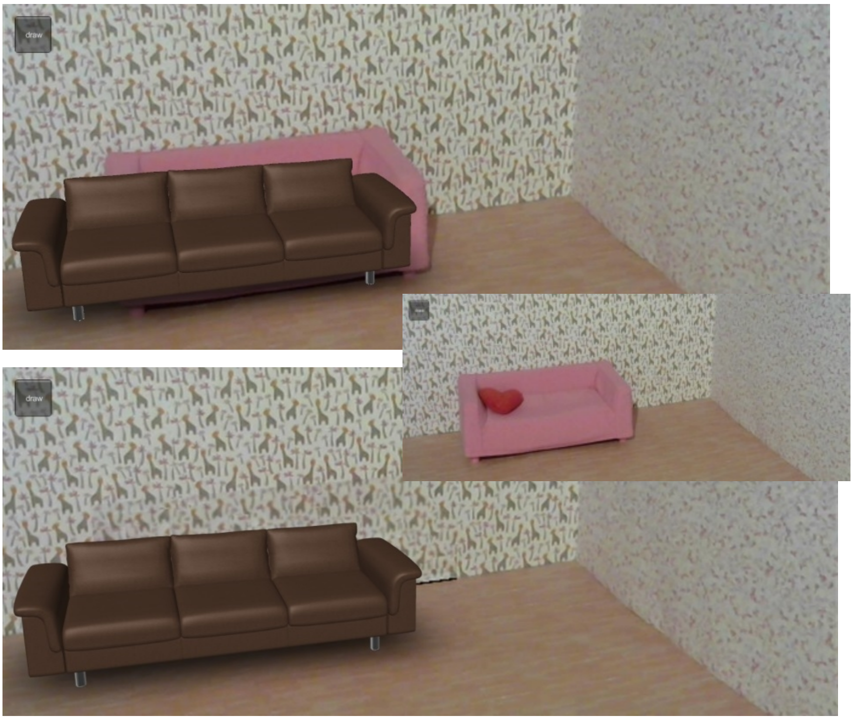


Figure 34. Top: A virtual object augmented over a real object looks non-realistic if the original object remains partially visible. Bottom: This disturbing overlap can be diminished from the background using diminished reality.

Diminished reality is a special case of video inpainting. Diminishing is carried out within an augmented reality application. The AR application tracks the movements of the camera and has information regarding 3D coordinates of the scene. This 3D information can be exploited in diminishing to improve the visual quality of inpainting. By definition, AR is a real-time technology and thus good performance speed of the diminishing method is crucial. On the other hand, the diminished area is often partly covered by augmentations, and the user's attention is focused on these virtual objects. Therefore, the quality requirements are more lax than with image manipulation tools (e.g. Photoshop), but speed requirements are tighter. In diminished reality, it is sufficient that the inpainting embeds in the environment and looks natural at an adequate performance speed.

Diminished reality functionality consists of several tasks. The application must identify the object to be diminished, decide which information to use for hiding the object, etc. Each task has special challenges and problems that need to be solved. In Paper VII we discussed these tasks, suggested solutions to the problems, and introduced enhancements to previous methods.

Exemplar-based inpainting methods copy samples from outside the area to be inpainted into the target area. In this way, the inside of the area resembles its surroundings resulting in a natural appearance. We used our own exemplar-based inpainting implementation. In addition, we presented a comprehensive modular pipeline for implementing diminished reality for indoor AR applications such as interior design. The modularized pipe-line is one of the important and unique contributions of Paper VII. Other substantial outcome is our methods of adapting the inpainting texture the current illumination.

In this section, we describe the diminishing pipeline, discuss our main improvements and insights, and describe how our implementation improves the diminished reality field.

We define the pipeline for diminished reality implementation as follows:

1. Select the object to be diminished, i.e., define the area to be inpainted, aka the *inpainting area*
2. Define the *source area* for texture generation
3. Determine the background 3D structures, i.e. planes constructing the background (positions of walls and floor)
4. Divide masks across the background planes, i.e. floor and wall planes in interior design
5. Rectify background planes and corresponding inpainting and source masks
6. Normalize illumination of the texture in the source area
7. Create inpainting texture using an exemplar-based method in rectified coordinates
8. Adapt the inpainting texture to real illumination conditions
9. Map the inpainted textures back to image coordinates
10. Render the inpainting texture on top of the original image

The source area can as well be defined after rectifying the background structures, in rectified planes.

We have implemented two possibilities for defining the area to be inpainted. The user can either select the area with the mouse or use a dynamic 3D volume, the dimensions and position of which can be changed by the user so that it covers the object to be diminished (Figure 35). The first approach is intended for still image usage and the latter also for real-time usage. Both approaches have the advantage that the selection task is easy to explain to the user and easy to perform. In addition, both approaches are robust and reliable, which makes them suitable for consumer applications.

Researchers have also presented more sophisticated methods for extracting objects, based on 3D reconstruction, feature detection and segmentation. These methods, however, often require some understanding of the underlying methods, and the selection may thus fail if the user is inexperienced. We chose to rely on simple user interaction; nonetheless the inpainting algorithm is independent of the way the inpainting area is defined. Kawai, Sato and Yokoya (2014) have presented a similar approach where the diminished area is divided into planes in 3D. However, our approach differs in couple of aspects; we use user interaction to define planes and therefore are able to diminish walls without any trackable features, whereas Kawai et al. detect planes using feature tracking, which works only with textured planes.

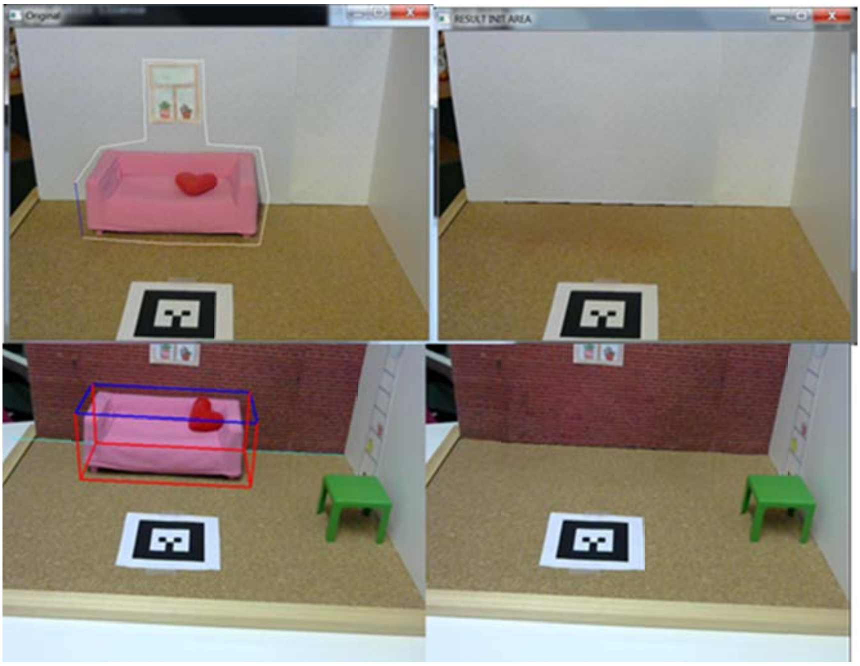


Figure 35. Two ways of selecting the area to be inpainted were used: selecting with a mouse (above), and selecting with a dynamic 3D volume (below). On the left are the original images with the selection illustrated, and on the right the diminishing results.

The inpainting result and speed can be optimized through appropriate selection of the source area for texture generation. Our solution uses an exemplar-based method for inpainting. In the exemplar-based method samples are matched with the inpainting area. The bigger the source area, the more matches there are to compare. Thus, the processing time increases exponentially as the source area increases. On the other hand, the source area should have enough suitable samples to enable good visual results. However, the source area should not contain any interfering samples, such as nearby objects that spoil the visual result (Figure 36).

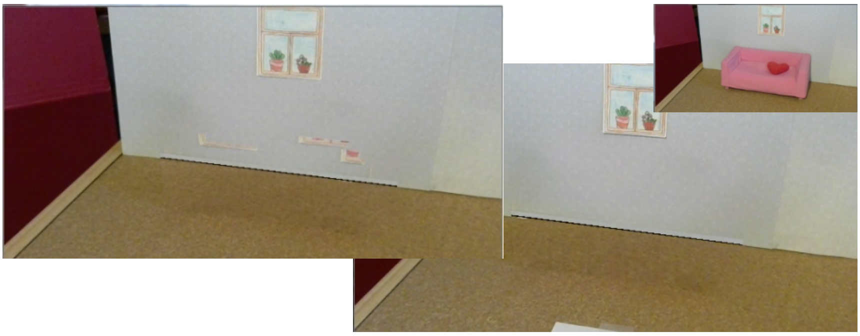


Figure 36. In the upper image samples belonging to the window are accidentally copied in the inpainting texture as the source area is not limited properly, whereas in the lower image the source area is limited to the area close to the diminished area, and no interfering samples are copied. The small image presents the original view before diminishing.

In our implementation the source area is limited to the area adjacent to the inpainted area, an N pixels wide area around the inpainting area, for example. In Paper VII we also discuss how to select the area with segmentation methods. The user can also indicate the source area and select the most appropriate areas. The inpainting algorithm is independent of the way the source area is defined.

The source area and inpainting area are presented with masks, where the area itself is marked with ones, and the outside of the area with zeros. The inpainting mask (diminishing mask) is marked $\mathbf{M}_D$ and the source mask $\mathbf{M}_S$.

The inpainting texture is created block wise, and the blocks are processed on the edge of the inpainting mask area. Part of the processed block is inside and part of it outside the diminished area. The matching blocks are searched from the source area (Figure 37).

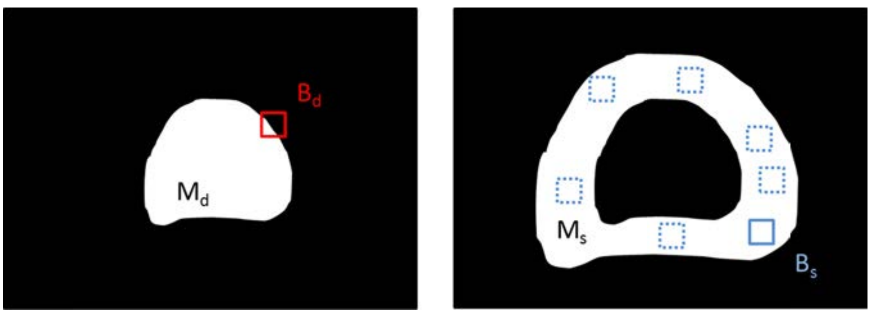


Figure 37. The best matching block for block $\mathbf{B}_d$ is searched from the source area.

The method only uses blocks that provide enough information for texture generation. In practice, this is ensured when at least a given amount of pixels, *p,* are located outside the mask (Figure 38).

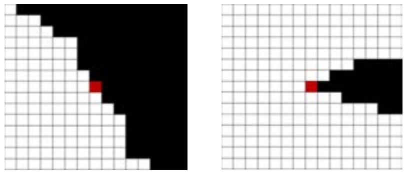


Figure 38. The left block contains enough information for texture generation, the right block does not. The centre pixel of the block is marked red (Paper VII).

The dissimilarity between the the blocks is defined as:

$$d(\mathrm{B}_D, \mathrm{B}_S) = \sum_{i,j} (1 - M_D) d(\mathrm{B}_D(i, j) - \mathrm{B}_S(i, j)),$$

where $\mathbf{M}_{\mathrm{D}}$ is the mask block corresponding to $\mathbf{B}_{\mathrm{D}}$, and k is the number of zero pixels in block $\mathbf{M}_{\mathrm{D}}$, $k > p$. If $k \leq p$, the block is omitted.

For RGB images, all channels all equal and the scalar product is used, i.e.

$$d(r,\ g,\ b) = (r,\ g,\ b)^{2} = r^2 + g^2 + b^2.$$

For YUV images one can weight the intensity values, e.g. the following metric is used

$$d(y,u,v) = ay^2 + bu^2 + cv^2,$$
$$\text{where } a > b,\ a > c \text{ and } a + b + c = 1.$$

The best matching block $\mathbf{B}_{\mathrm{best}}$ for block $\mathbf{B}_D$ is the one that minimizes the dissimilarity to it

$$\mathbf{B}_{\mathrm{best}} = \arg\min_{\mathbf{B}} d\left(\mathbf{B}_D - \mathbf{B}\right),$$

where **B** belongs to the source area of the source mask. The new pixel values for block $\mathbf{B}_{\mathrm{D}}$ are

$$\mathbf{B}_D^{new}(i, j) = \begin{cases} \mathbf{B}_D(i, j), \text{if } \mathbf{M}_D(i, j) = 0 \\ \mathbf{B}_{\mathrm{best}}(i, j), \text{if } \mathbf{M}_D(i, j) = 1 \end{cases}.$$

The mask is updated accordingly

$$\mathbf{M}_D(i, j) = 0,\ \forall i, j.$$

Our method first fills in areas containing edges; in ensures that texture boundaries, such as tiles, are mostly repeated nicely.

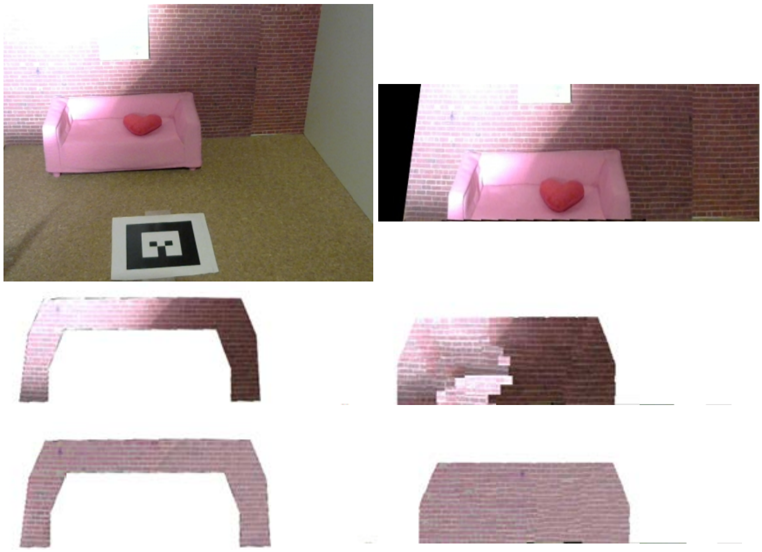
Figure 39. Example of problems with exemplar-based inpainting with a strong contrast image where samples of intermediate darkness are rare. The small images show the original image (cf. Figure 47 where normalization is used).

A common problem in real indoor diminishing applications is that one side of the diminished area is much darker than the other, and mid-darkness or transition samples are rare. In this situation, the exemplar-based method copies either dark or light samples, resulting in blocky, clumsy visualization (Figure 39). To overcome this problem, we propose normalizing the global illumination of the source texture before creating the initial inpainting texture (Figure 40).

The normalized pixel value *S* at point (x, y) is

$$S'(x,y) = S(x,y) - M(x,y) + A,$$

where *S(x,y)* is the original pixel value, *M(x,y)* the median of the *NxN* block with the centre at *(x, y),* and *A* is the average of all median values in the source area. Each channel is processed independently. Local variations are preserved, as local median values are used for normalization. Illumination normalization is carried out in the YUV colour space. The normalized texture is adapted to the current illumination before rendering, as we will explain later.



source area *inpainting area*

Figure 40. Initialization in the presence of lights and shadows: neutralizing the source texture before inpainting yields a smoother texture. The neutralized texture must be adapted to the illumination. Top: original image and rectified wall texture. Middle: source texture and inpainted texture without neutralization. Bottom: source texture and inpainted texture with neutralization. (See Figure 46 for similar setting with completed inpainting).

Another typical problem is perspective distrortion. In the perspective view, texture elements are bigger on one side and smaller on the other, while texture samples of intermediate size are rare or absent, and parallel lines in the 3D coordinates are not parallel in the image (Figure 41).

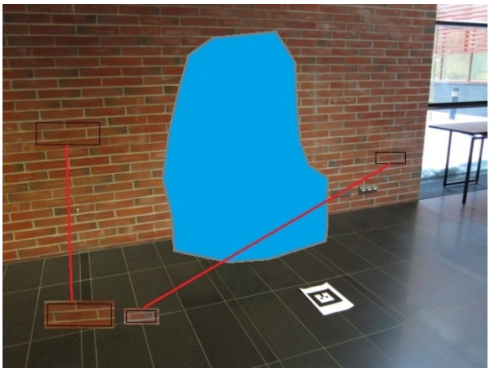


Figure 41. In a perspective view, texture elements are bigger on one side of the diminished area and bigger on the other. Texture samples of intermediate size are rare. Parallel lines are not parallel due to perspective transformation (e.g. lines between floor tiles).

Removing perspective before inpainting mitigates the problem of missing texture samples (Figure 42). Thus, it is beneficial to create the inpainting texture in rectified coordinates. In interior design, textures are mainly created for planar walls and floors, which are easy (and fast) to rectify.

Figure 42. Comparison of texture generation in image coordinates (left) and rectified coordinates (right).

Using homogenous coordinates, the system can map world points X to image plane x with the camera transformation matrix

$$\mathbf{x} = \mathbf{MX}$$

(see e.g. Hartley and Zisserman 2000:7). The camera transformation matrix M is known as a result of the AR tracking module. The marker-based tracking system places world coordinates on top of the marker. This means that the origin, x and y axes are on the floor plane, and the z axis is upwards. If the coordinate axes are located differently, another transformation matrix is needed to transform the coordinate axes accordingly. Thereafter, the calculations are the same.

The method maps the diminished area to the floor plane. The system then finds an “optimal” rectangle around the diminished area; the diminished floor area and floor source area are inside the rectangle, with one edge running along the wall line (Figure 43). In practice, it is a rectangle with one edge aligned with the wall. If the object is in the middle of the room, the area that it covers becomes bigger and the application must inpaint bigger areas in 3D coordinates.

The transformation matrix **M** transforms the rectangle’s corner points $\mathbf{P}_i$ to image points $\mathbf{p}_i$

$$\mathbf{p}_i = \mathbf{M}\mathbf{P}_i.$$

A homography is a 2D projective mapping between homogenous coordinates. It is a perspective projection from one plane to another and represents, for example, how a world plane is mapped to the image plane in a pinhole camera. Thus, with a homography, the system can transform a world plane from image coordinates to rectified texture coordinates (Figure 43). A homography between two planes can be calculated if at least four corresponding points are known from each plane. The rectified texture has the same aspect ratio as the rectangle on the floor.

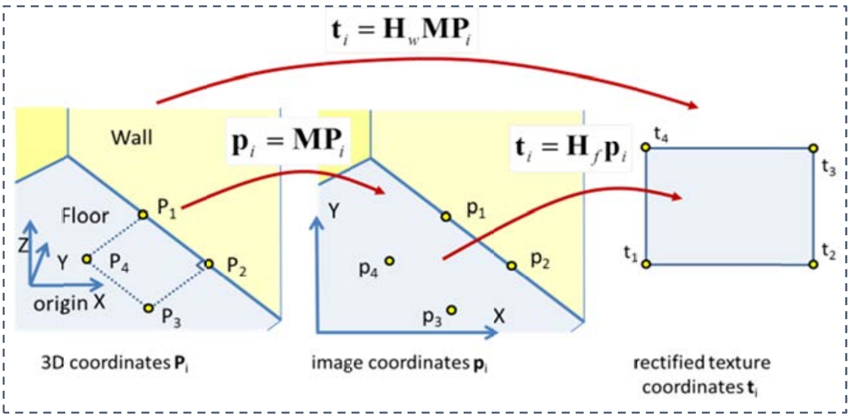


Figure 43. Rectifying the floor plane (Paper VII).

The homography $\mathbf{H}_f$ between the image coordinates and the rectified texture is such that

$$\mathbf{t}_i = \mathbf{H}_f\mathbf{p}_i$$

is calculated using the four corner points of the texture $\mathbf{t}_i$ and the corresponding image points $\mathbf{p}_i$, i = {1,2,3,4}. This homography is used to rectify the floor texture (Figure 43).

A homography between wall and image planes is calculated in a similar manner. An "optimal" rectangle on the wall is first deduced and then the rectangle corner points are mapped on the wall $\mathbf{P}_j$ to the image plane

$$\mathbf{p}_j = \mathbf{M}\mathbf{P}_j.$$

Next, the homography between the rectified texture and the image using corresponding texture points $\mathbf{t}_j$ and image points $\mathbf{p}_j$, i = {1,2,3,4} is solved using the equation

$$\mathbf{t}_j = \mathbf{H}_w \mathbf{p}_j.$$

This homography, $\mathbf{H}_w$, is used to rectify the wall texture.

The rectified inpainting textures are mapped back to the image plane with inverse homographies

$$\mathbf{p}_i = \mathbf{H}_f^{-1}\mathbf{t}_i \ \text{ and } \mathbf{p}_j = \mathbf{H}_w^{-1}\mathbf{t}_j.$$

After initialization, the inpainting texture is not updated, but adapted to the current illumination. Without adaption the illumination texture would be immediately apparent when the illumination changes (Figure 44).

Figure 44. Frames without (top) and with (bottom) adaption to current illumination; the small image shows a frame before diminishing. The inpainting texture was created from a lighter frame.

For the adaptation *control points* are selected from outside of the diminished area in 3D coordinates. The number of control points depends on the resolution used for the illumination texture; they are selected from same low-resolution grid, but from immediately outside the inpainting area. Their positions are mapped to 2D texture coordinates for each frame (Figure 45). The changes in illumination between frames are examined at these control points.

For each frame the method creates an *illumination adaptation texture*. In order to optimize the processing time, the illumination adaptation texture is presented at lower resolution than the inpainting texture.

As the source texture is normalized before initialization, adaptation must be also done in the initialization phase of the inpainting texture. In the initialization a higher resolution is used for the illumination adaption texture.

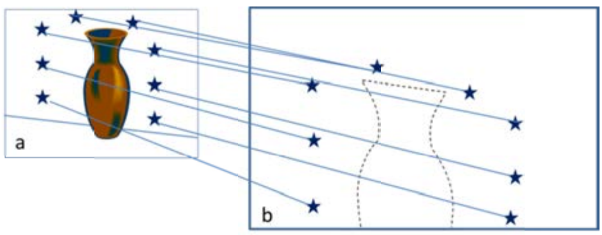


Figure 45. Control points around the area to be diminished are selected in 3D (a). For each frame, their positions are mapped to texture coordinates (b). The illumination changes are calculated at these control points and blended over the inpainting area.

The effect of control points should be inversely proportional to the distance. This happens when the values of the points inside the inpainting area are, for example, calculated using inverse distance weighted interpolation aka Shepard's method (Shepard 1968). To enable faster calculation, we modified the Shepart's method. The value at point **x**, *I(**x**)*, is the inverse weighted average of N control points' values *I(*$\mathbf{c}_i$*)*

$$I(\mathbf{x}) = \sum_j \frac{1}{\left\|\mathbf{x}-\mathbf{c}_j\right\|} \sum_i \frac{1}{\left\|\mathbf{x}-\mathbf{c}_i\right\|} I(\mathbf{c}_i).$$

The norm used defines the attenuation speed of the influence of each control point. Our implementation uses a Euclidean norm to the fourth power

$$\left\|\mathbf{x}\right\| = \left\|(x,y)\right\|_2^4 = (x^2+y^2)^2.$$

This gives natural attenuation of light sources in indoor scenes (Figure 46).

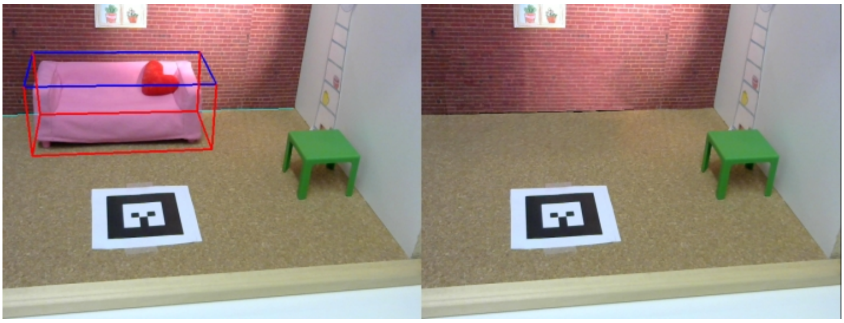


Figure 46. Example of adaptation to illumination change: original image on the left, and inpainted image (with adaptation to lighting) on the right.

The number of control points affecting each point inside the inpainting area is limited. In order to have influence from all directions, yet a low number of control points, we select the nearest control points in 1–8 compass directions. Directions where there is no source texture are omitted. The approach has been adjusted to create natural looking smooth transitions from one colour to another, while keeping the processing time low.

The illumination adaptation texture is created with low resolution and then the rest of the pixels are interpolated using bilinear interpolation.

Instead of using true values for control points, we use the difference compared to the initialization moment. Thus, the created illumination adaptation texture represents the *illumination change* and the adaptation is accomplished by adding the illumination adaptation texture to the inpainting texture:

texture for the frame = *the inpainting texture* + *the illumination adaptation texture*.

The adaptation texture has some artefacts due to the way it is generated and due to interpolation. However, mixing the high frequency inpainting texture with the low frequency adaptation texture fades the artefacts and the result looks natural. This adaptation to current illumination is new in diminished reality.

In real time implementation, only steps 1, 8, 9 and 10 are repeated after initialization. The illumination adaptation texture in step 8 is calculated at much lower resolution than the original texture. In step 8, the (inverse) homographies are calculated. Our diminished reality implementation performs in real time, which makes it suitable for augmented reality usage. The non-optimised code, which e.g. contained unnecessary image copying, run typically 13–15 fps. An optimised code would allow use of diminished reality in applications requiring 25–30 fps.

4.2.3 Research outcomes concerning AR in interior design and diminished reality

The AR interior design solution was developed for ordinary users, taking the user requirements into account and paying close attention to the user experience. The AR field has advanced considerably since the original publication of Paper VI, both in technology and devices. As our user studies (presented in Chapter 3) show, however, the user-related issues discussed in Paper VI are still relevant.

According to the users, realistic, adaptive lighting and shadows are important and improve user experience (pages 44 and 47). A flexible user interface design that allows the user to choose how to interact with the system is also worth noting regarding UX.

The diminishing methods presented in Paper VII solve one of the bottlenecks identified for serious use of AR interior design solutions: the ability to remove existing furniture virtually (see Chapter 3).

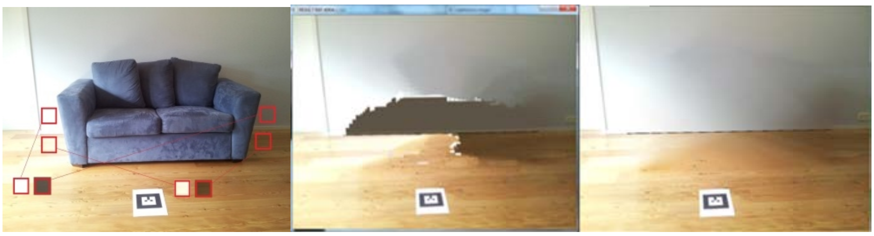


Figure 47. Our solution can handle large illumination variations during initialization of inpainting texture. Images from left to right: Original image, inpainting without texture normalization, inpainting with texture normalization.

Our pipeline for diminished reality contains a unique solution for adapting inpainting texture to changes in illumination; first by normalizing the source texture before initializing the inpainting texture (Figure 47), and then adapting the texture in real time to the current illumination (see Figure 44, p. 80 and Figure 46, p. 82). This noticeably improves the visual quality of diminishing in typical indoor situations.

We also proposed utilizing the 3D information available in AR applications, and performing inpainting in rectified coordinates. The visual result of inpainting is clearly improved by this approach (Figure 48 and Figure 42, page 78).

We modularized the diminished reality pipeline, thus making it easy to change methods and algorithms for different tasks. This ability to combine different methods supports diminished reality research and advances the field as a whole.

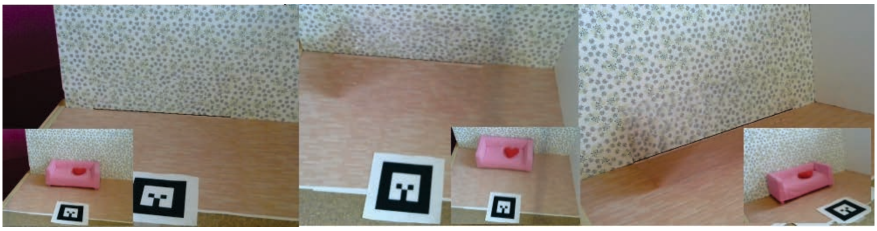


Figure 48. Examples of a perspective view with inpainting executed in rectified coordinates. A shadow of the real object remains, although the object is removed. Yet the texture looks natural.

Our diminished reality solution works in real time, making it ideal for AR applications.

Our diminishing solution is based on methods that require no technical skill or understanding of the underlying methods. Thus the implementation is suitable for the ordinary consumer.

4.3 Real life examples using AR in interior design

In this chapter we present three real life examples and users' comments regarding the use of a real AR interior design solution.

4.3.1 VividAR

VividWorks[24] is a software company that offers online 3D design-to-purchase SaaS platform solutions for furniture manufacturers and retail chains. We co-operated with VividWorks on the AR-Sisustus and CloudSW projects, for example (see page 69 for details).

As augmented reality is a natural extension to 3D design software, VividWorks also offers an AR platform called VividAR™ [25], the marker-based version of which uses the ALVAR library for marker detection and marker hiding (Figure 49).

Our diminished reality functionality has been integrated into the developer version of VividAR. We observed three real use cases using the diminished reality enhanced VividAR, and we will next discuss our observations from these trials.

---

[24] www.vividworks.com
[25] http://youtu.be/YxY146gzziQ

Figure 49. The interior design service of the ASKO furniture retail chain runs on the VividAR platform. The room is real with virtual furniture and plants augmented onto the image (Image courtesy of VividWorks).

4.3.2 Real use-cases with VividAR enhanced with diminished reality

As a follow-up to the research described earlier in this work, we conducted a small-scale real-use experiment with an interior design application. The unpublished study serves as a validation of the work done and as a guideline for future development. Three users tested the developer version of VividAR for carrying out interior design. The users were 23–42-year-old females. The first user was preparing to move house, and so the application was tested in a real situation in her new apartment. The second user had recently moved and had experience of kitchen renovation planning and interior design using online home design services. The third user had no recent interior design experience. The users tested both a tablet (iPad) application and a web application (Figure 50).

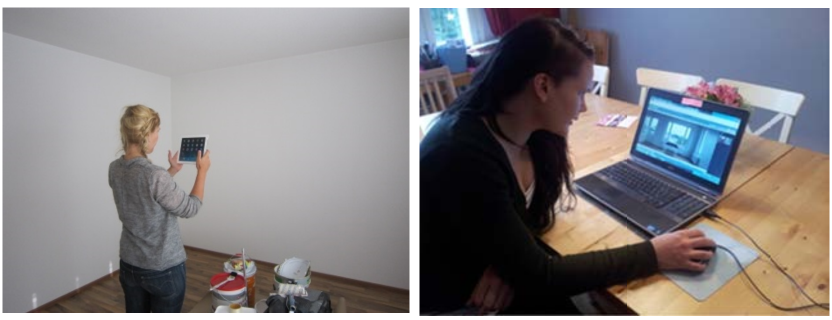


Figure 50. Users testing the tablet application (left) and the web application (right).

In the first use case, the apartment was expected to have been empty and the interior design task thus a straightforward augmentation. However, a number of tools and equipment had been left in the living room, thus making the diminishing feature both necessary and valuable (Figure 51).

Figure 51. The first user's living room: a real situation where the diminishing feature proved valuable. Above: augmentation without diminishing. Below: augmentation with diminished reality.

The second user also spontaneously commented as follows regarding the usefulness of the diminished reality capability: "*the apartment was literally full of removal boxes and other stuff right after the move – just when you wanted to be getting on with planning the decorating and getting in new furniture*".

Another highly appreciated feature was virtual mode, which enables the user to observe virtual furniture from any viewpoint. The users shared the opinion that the AR application helps the user to perceive dimensions. Particularly with respect to furniture size it helps in determining whether furniture fits a desired space. The users also expressed the wish to be able to obtain floor plans from the application.

The users experienced some difficulty noticing when a piece of furniture had been moved so far away that it was actually outside the room. They proposed that virtual furniture should stop at the wall, and if brought near a wall, should snap against it. They also proposed that the application should automatically position on the wall any objects that are normally mounted on a wall, such as picture frames and wall cupboards. The application should also allow the user to move such objects along the wall to the desired position.

When planning to buy new furniture or considering a new interior design, consumers typically spend considerable time experimenting with online home design tools and browsing furniture retailers' websites. An AR interior design tool that connects these resources was considered a significant step forward, and it was thought that the tool should also contain a comprehensive collection of virtual furniture products, e.g. from a specific retail brand. The test users thought that *"a good tool would engage the user, they would then spend more time on the service, and would probably end up buying products",* and that people could also use the AR interior design service "*to give instructions to a removal company"*.

The desired features were similar to those recorded from previous in co-creation sessions and focus groups presented in Chapter 3. Other comments were more related to implementation of the application rather than its technical features (e.g. order of the menu items).

5. Results – Answers to the research questions

We have earlier presented outcomes of each study and development case. Now we summarize all these together and see how the presented research answers to the research questions set in Section 1.2 (page 15).

5.1 RQ1: How to involve users in the design process to create more effective AR experiences?

Our hypothesis was that user-centred and participatory methods are able to reveal user expectations of emerging technologies such as augmented reality. This proved to be valid; we were able to identify the users' expectations. In the following, we review the research methods used and analyse their validity.

We chose to use a combination of user-centred methods with different target user groups to support our overall research goal. The different user groups presented many similar ideas and complemented the general view.

In augmented reality field, the development has been technology-driven and only recently there has been more user-centric approaches (Swan and Gabbard 2005; Dünser, Grasset et al. 2007). The users have been for example involved in testing visual perception issues and task performance as well as in developing interaction techniques and user collaboration (Swan, Gabbard 2005; Shen, Ong and Nee 2010). Users have been involved in lesser amount in design phase of augmented reality solutions, and although co-design is established method in other fields, it has been rarely used in designing of augmented reality solutions[26]. Our work was emphasized on user involvement in the design and implementation phases of the development cycle (see page 18), which makes our work particular.

[26]In February 2015 Google Scholar listed ca. 96 000 articles with the keyword "augmented reality", ca. 61 400 articles with "co-design", and only 877 with "augmented reality" AND "co-design". This means that roughly 0,9% of all augmented reality research utilised co-design, and 1,4% of co-design research concerned augmented reality.

We conducted several studies at different stages of developing interior design solution and with different user groups. The users were involved in sketching the not-yet-existing service (Section 3.3), in determining required features of a future service (Sections 3.4 and 3.7), in testing, evaluating and further ideating during the development phase (Sections 3.4 and 3.5), and evaluating and testing of the implemented service (Sections 4.3.2 and 4.1.2). In addition, users were involved in testing multimodal user interface for assembly type tasks (Section 4.1). The combination of several user-studies with different groups at different stages of development process makes the extent of our research unique in AR field, and novel in interior design field.

We were able to verify that **the users are able to produce useful ideas regardless of their knowledge of the underlying technology and regardless of the phase of the design process they participated**.

Parallel studies supported each other, and for example business actors who have been part of an AR interior design value chain presented similar ideas as we used in scenarios, thus validating them.

On the other hand, there was also variation between the user groups, which had different needs and opinions regarding functionalities and preferred ways of using the service. Particularly, professional users and consumers had different expectations regarding the interior design service. Also in other studies, different users groups tend to have different expectations and preferences for the use of AR (see e.g. Ventä-Olkkonen, Posti, Koskenranta and Häkkilä 2012, Mosiello, Kiselev and Loutf 2013). Thus, a one-size-fits-all approach to application/service design might fail. User involvement in the design phase helps to take into account the expectations of the specific target group.

Our research verifies that user-centred and participatory methods are well suited to discovering user expectations regarding AR services. In addition, involving several different user groups in the early stages of concept design proved to be valuable for two reasons: it gave a good general view of the subject, and revealed differences between user groups. The latter is especially important if the target users belong to several user groups. Involving different actors and user groups in sketching digital services enables to figure out a feasible ecosystem. A viable ecosystem is essential for service providers and to the existence of AR service in the first place. In the literature, co-design has been seen as useful to the service design process as well as to both users and service providers (Steen, Manschot and Koning 2011). Our outcomes in both application areas (interior design and hybrid media) are in line with these results.

As explained above, the users can be involved in various ways to the design process to create more effective AR experiences.

With user-centred and participatory methods, we were able to reveal a great number of user expectations, fulfilling of which is essential for good user experience. Next, we will discuss these expectations regarding interior design.

5.2 RQ2: What are the user expectations regarding AR interior design?

First of all, our studies confirmed that there is a need for easy-to-use tools for consumers as well as for professionals and pro-users working in the area of interior design (Paper III).

Our investigation of AR service requirements began with a vague concept of an ambient home design service. Firstly, we sketched the potential users, service providers and functionalities of such a service (Figure 52). During this sketching process, the participants raised a number of issues related to business factors and other relevant topics that are worth consideration when developing the service.

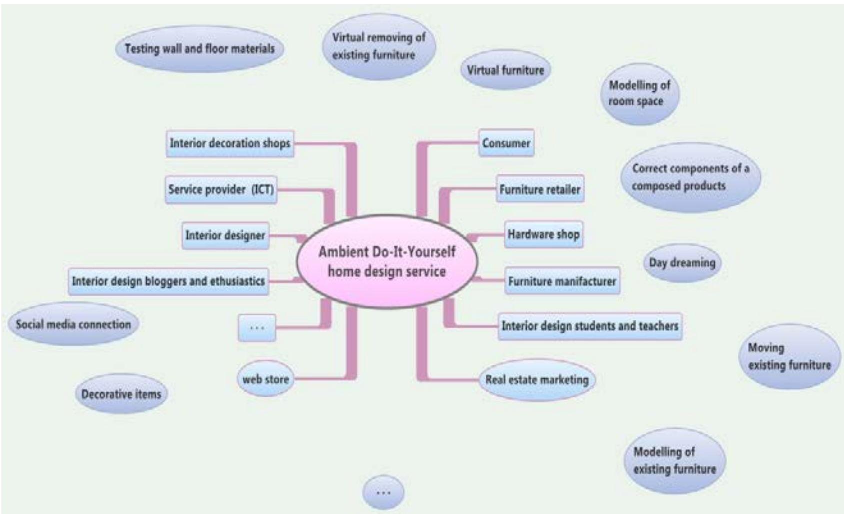


Figure 52. A mindmap of potential users, service providers and functionalities of an *ambient home design service*.

Thereafter, we focused on a narrower concept of AR interior design service and its characteristics, including business attributes. Next, we discuss those results and answer RQ2.

According to our studies, user expectations regarding AR are generally similar to those for any other technology; there must be **a need to use the technology** (see e.g. page 47), and the technology should be **easy to use** (see e.g. pages 43 and 54). ‘Need’ here means that the technology solves a problem or makes tasks easier. In the case of interior design, AR enables the user to test different furniture and interior designs effortlessly, without any physical work. Ease-of-use and need go hand in hand; people are prepared to invest effort if the expected benefit from using the technology is high (see e.g. page 47). This observation is in line with the technology acceptance model (see page 36). People also perceive use as easier when the benefit is higher (Davis 1989). Therefore, during the service development process it is important to focus on **the aim of use**, keeping in mind *what the user is supposed to achieve by using the application or service*.

Figure 53. A mindmap of AR interior design service features. Must-be features are marked with red flags and other important features are marked with orange flags.

In the interior design context, the aim of use for ordinary people is testing interior design elements in a real home environment as an occasional pastime activity. Ease-of-use is paramount and, especially, first-time use should be effortless. For professional users, the aim of use is to produce an interior design plan and the technical requirements are higher. Professionals can use the service only if certain existing bottlenecks are solved, such as the ability to remove existing furniture virtually.

After determining user expectations, researchers often end up with (too) many options. The number of desired features may be vast, expectations may be contradictory, and different user groups may have contrasting opinions (see Figure 52 and Figure 53). In this situation one must **select the best or most important features for further development.** As we discovered, a viable business model is essential for a successful AR service. Thus, one selection criterion is to **choose a viable business model** as a basis for further development. Another way to limit the work is **to focus on the most prospective target users and user groups**.

Even then, the number of requirements that the users propose during co-creation might be large, in which case one **needs to reduce the number of features** to be implemented. One possible means of limiting features is to categorize the features according to physical function and user-satisfaction. Kano (2001) and Kano, Seraku, Takahashi and Tsuji (1984) propose following categorization: *Attractive quality elements*, which can give user satisfaction if functional although the user can tolerate a lack of these elements; *One-dimensional quality elements,* which can give user satisfaction if functional, and cause dissatisfaction if dysfunctional; *Must-be quality elements,* whose function is always required and which cause dissatisfaction if dysfunctional.

Must-be quality elements are bottlenecks of the service, without them, the service is not feasible. One-dimensional quality elements have a great impact on user experience and are thus important; hence, the technical solution must be reliable. Attractive quality elements can improve user experience, but are not vital to the service – they are not the first features to develop and implement.

Figure 53 shows **user expectations regarding features of the service**: must-be features (red flags), important features (orange flags) and nice-to-have features; and **user experience related viewpoints**: easy-to-use, engaging, fun-to-use.

In this work, we focused our application and algorithm development on selected one-dimensional quality elements and must-be quality elements (see Table 3). These elements fall in two categories: important features (e.g. ease-of-use, multimodality) common to several fields of AR and critical, application independent bottlenecks of AR interior design service (e.g. diminished reality). Application independent means that those elements serve the whole application area.

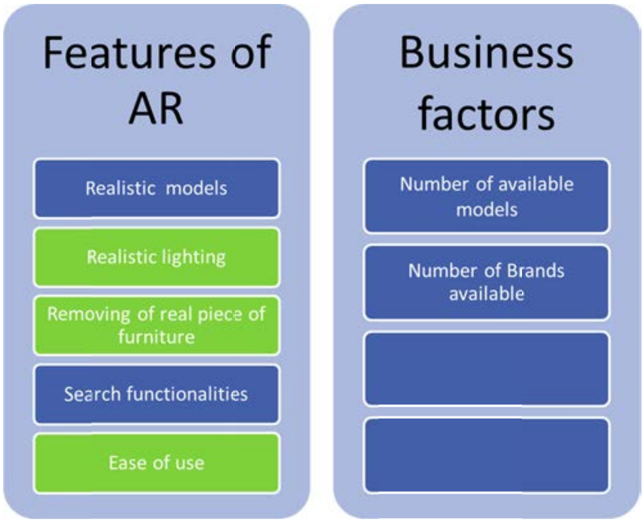
5.3 RQ3: Which technical solutions fulfil the user expectations and improve the user experience of AR?

For the user, a good user experience consists of easy and pleasant use of the application and satisfying results. For the service provider, good UX means that the service is easy to deploy and supports the business network's activities (Väänänen-Vainio-Mattila, Oksman and Vainio 2007). In other words, the digital service needs to be valuable to the user, in addition to being useful, usable and desirable (see e.g. Morville 2004). Next, we consider how these observations are reflected in our studies regarding AR interior design service.

Earlier, we identified user expectations for AR interior design (see e.g. Figure 53). **Fulfilling these expectations** is what is primarily needed to improve the UX. **Solving critical challenges and bottlenecks** makes the service valuable and usable for the user. Enabling other desired features makes the service desirable and pleasant to work with. In other words, one must **consider the special characteristics of the task during the development process**. Other expectations that the users highlighted were related to ease-of-use and satisfaction – i.e. factors affecting to the UX.

A few important issues emerge here. Firstly, as AR is an area where photorealistic rendering is appreciated, realistic lighting and shadows are therefore essential. Dimensional accuracy is also crucial when deciding whether a piece of furniture fits in an existing space. Secondly, interior design is seldom used for empty spaces. Typically, the space is occupied with existing furniture and occlusions and collisions occur between real and virtual objects. Solving these issues improves the user experience considerably in interior design and similar AR applications.

Table 3. Bottlenecks in AR in interior design. The solutions to bottlenecks marked green are presented in Chapter 4.



In Chapter 4, we focused on developing solutions to essential bottleneck issues (see Table 3). Business factors – number available models and brands – are in the hands of the owner of a commercial application. It is also the hand of the application owner to implement adequate search functionalities, and to create realistic 3D models. Thus, these issues are acknowledges as important, but they are not studied further. Instead, this work focused on application independent features of AR; realistic lighting, removing real piece of furniture (diminished reality) and ease of use. This development work improves the UX and makes AR deployable in consumer applications.

Chapter 4 began with a discussion of augmented reality assisted assembly, and the benefits of a multimodal user interface. We then continued with the development of an AR application for interior design, and finally focused on diminished reality. Next, we will examine how the research described in this chapter contributed to the research questions, and how the described research has advanced AR towards real use.

UX was shown to play a significant role in the adoption of AR technology. The study also succeeded in identifying the key factors affecting its adoption, and to find factors that affect the user experience.

The purpose of using augmented reality is to aid the user in a meaningful way. In assembly applications the system is used to guide the assembly pipeline. In interior design AR is used to visualize interior design plans. Users find it important that they know what is happening and feel that they are **in control of the system** (page 66). In assembly this means, among other things, that the user is aware of the current task and knows when the task is completed and when a new tasks starts. One key issue for this is **adequate feedback from the system** and **verification of completed tasks** (page 65). The feedback should reach the user. It is important that fonts, colours, animations, etc., **catch the user's attention and help the user to focus on essential things** (page 65). In other words the assembly system should **guide the user's attention in a helpful way**. The system could also utilize audio feedback and other modalities. Verification of completed tasks could also be built-in, as discussed in Section 4.1.3.

Individuals have different preferences regarding how they wish to interact with the system. Our research shows that a **possibility to interact with the system in a preferred way improves the user experience** (e.g. page 65 and 69). In paper V, we run user tests on multimodal user interface for augmented assembly and noted that **multimodality is one way to improve the user experience** of this kind of applications.

For interior design our observations on benefits on interaction alternatives in user interface are more heuristic (Paper VI). These findings are in line with user-centred design principles; which indicates that the result is generalizable for different types of AR applications. As for the interior design, we also noted that different users have different expectations for a system; the consumers prefer an easy-to-use and simple system, the professional user desire more features and interaction options (Paper III, page 47). These kinds of expectations could be fulfilled by giving the user a possibility to select the way of interaction with the system (e.g. different user interface options).

The system should **support the purpose it is used for**. Users often have high expectations and the number of desired features can be high (see Section 5.2). It is therefore important to identify "must-be features" and **solve bottlenecks** that would prevent or hinder the use of the solution. In AR interior design, **diminished reality** solves a serious bottleneck against using the solution for producing real interior designs. For AR assembly this means, for example, that the setup, the devices and the environment should be such that the assembler is able to work normally and in one way or other more efficiently than without the system. For interior design, the learning phase should be relative for the use purpose: consumers are not willing to use time for learning to use the application, whereas professionals are ready to invest time on learning if the benefit is high enough (e.g. to be able to do valuable tasks). These findings can be summed up as: **The cost of using the technology should be lower than the benefits**.

In interior design, we chose to use **robust methods of diminished reality** in order to minimize the risk of anomalies, such as the tracking failing. For example, for selecting the object to be diminished and detecting the wall position our implementation uses **simple interaction, which allows the user to be in control of the system**.

We studied solutions that enable the users to choose how they interact with the system. A **multimodal interface** allows the user to select their preferred mode of interaction with the assembly system. The **flexible user interface** presented for interior design allowed the user to select the most convenient way of interacting with the AR system (see pages 69 and 83). We showed earlier that **the number of supported features** should support the needs of different user groups. **User interface should support individual choice of how to interact with the system, and user group and use purpose dependent factors should be supported by the design and the user interface.** By user group and use purpose dependent factors, we mean that the setup should be suitable for the purpose and task in question and the supported features should support the purpose of the application. What works for an assembler in a factory is not necessary suitable for an interior designer decorating a customer's home.

To support the task that the application is used for, all bottlenecks preventing such use should be removed. In interior design, we identified a lack of diminishing capability as a crucial bottleneck preventing real use of AR in interior design. To overcome this, we developed a **diminished reality solution**. Another serious concern in AR is performance speed; low performance speed prevents use of technology in real-time applications. All of our implementations (assembly, interior design, diminished reality) work in real time.

The rendering approach depends on the application area. Non photorealistic rendering best supports assembly-type applications, whereas photorealistic rendering supports the aims of AR interior design. In assembly tasks, clearly distinguishable augmentation is need to steer the user's attention to the desired objects or functions. In interior design, the goal is to create a realistic scene by embedding virtual objects with photorealistic rendering.

Illumination plays a key role in supporting the purpose of an AR interior design application. We therefore developed **virtual light sources** that the user can position freely, and the characteristics of which the user can adapt to real environment. Our implementation also allowed the user to **adapt the ambient illumination of the virtual scene** according to the real environment. This approach **improves the visual quality and the user experience in AR interior design** (see pages 44, 47, 59 and 83).

Figure 54. An example of using diminished reality in an AR application for construction visualization. On the left, the buildings to be demolished disturb the AR visualization of the new construction plans. On the right, the visualization result is clearly improved through diminished reality.

Illumination also needs to be taken into account in diminishing. We therefore developed a **diminished reality solution that adapts to illumination conditions** (see e.g. Figure 44, Figure 46 and Figure 47). Implementing this solution in AR interior design applications will have a great impact on the possible use cases for AR in interior design. The diminishing ability is also a **useful feature for other application areas**, such as building and construction visualization as well (Figure 54).

In this work we focused on selected features and a natural continuation would be to implement rest of the identified features in the future. While adequate functionalities are essential for the user, a viable business model is needed for the service existence in the first place. Next, we discuss what our studies revealed about business factors supporting wide utilization of AR.

5.4 RQ4: Which business factors support the wide utilization of AR technology?

We studied business aspects in two different application areas of augmented reality: interior design (Papers I, II and III) and hybrid media (Paper IV). Although these application areas are different, we found many similarities at the concept level. Commercial actors viewed a viable business model as the most important attribute of the service. It is consequently beneficial to involve business actors in the design process.

In AR advertising in print media, we focussed on the value chain of the hybrid media concept and service ecosystem. In interior design, we focused on the service concept and its features.

From the user's point of view AR is not an end in itself, but a means of doing something. User satisfaction comes from completing the desired task. Often AR is a part of a larger system, a technology that supports visualization. Here, serious use of AR differs from games and other just-for-fun applications where AR might only be used for wow-effect. While AR can be used effectively in advertising to engage the user's attention, it is best applied as a part of larger digital system in a hybrid media context (see page 53 and Paper IV).

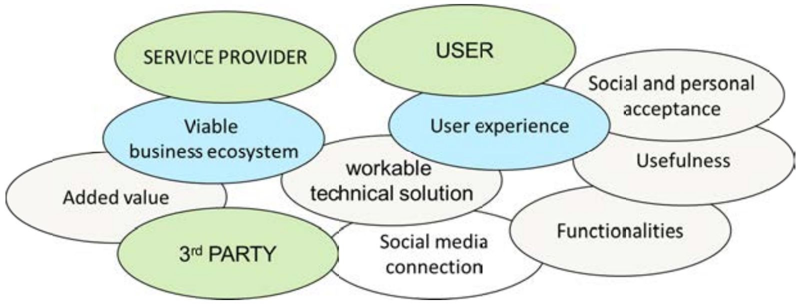


Figure 55. Sketch of the AR interior design service ecosystem.

A number of similarities regarding business factors arose in interior design and hybrid media. For both application areas **AR alone is not sufficient; the service ecosystem requires additional elements**. As for AR advertising, AR is seen as a part of a larger hybrid media concept (see page 53). In the case of interior design, in addition to technical features, several user expectations are related to business factors (see Figure 53, page 91). Thus, in addition to AR related issues, one must consider the whole service network. For example, fulfilling the "number of brands" and "complementary objects" features requires **developing the service ecosystem** to support them.

AR should be seen as a feature of a system and be considered a part of a larger system with many other features. This is common for many consumer-level applications. For example, AR world browsers (see page 27) have social media connection, they provide extra information such as timetables, menus, maps etc. and AR is only a part of the mobile service. In our earlier work with 2D barcodes, AR visualisation was also merely one possible application that the barcode launches, i.e. as a part of a larger service system (Siltanen and Hyväkkä 2006). Perhaps one should stop talking about AR applications and simply talk about applications (interior design application, hybrid media application, world browser application, etc.) as AR is often not the descriptive attribute. These applications may then have AR features, and AR may even play an important role in the application. Bernardos and Casar (2011) analysed business models of more than 400 mobile AR applications and noted that in many cases AR feature is added to existing application only to enhance user experience.

Figure 55 shows a sketch of the AR interior service ecosystem and the essential elements affecting it. The actors are the user, the service provider and a 3rd party (there can be several 3rd party actors and different users). For the user, the user experience is most important, and for the service provider a viable business ecosystem is essential.

A 3rd party actor can bring added value to the service ecosystem both for the service provider and for the user. In fact, 3rd party actors can be a necessity for a viable business ecosystem in some cases. We have listed some potential 3rd party actors for interior design in Figure 52 (page 90). These actors, such as a hardware shop, can enhance the interior design service.

One outcome of our studies regarding both interior design and hybrid media was that lack of standards hinders building such business ecosystems. For example, Lechner (2013) and Kim and Yoon (2014) also acknowledge the need for standards to enable further growth of the mobile AR field. Thus, **standards are important from business ecosystem viewpoint**.

A workable tactical solution is needed both for viable business and for a satisfying user experience. Other aspects affecting the user experience include, for example, social and personal acceptance, and the usefulness and functionalities of the system. The required functionalities and functionalities that bring added value depend on the purpose of use and the user. Social media connection may connect 3rd party actors to the ecosystem, but may also be essential part of the service and bring added value to both the user and service provider. For instance, interior designers may provide their services within the system.

The importance of the user experience to the success of digital services is widely acknowledged (see e.g. Karapanos, Zimmerman, Forlizzi, and Martens 2009). Augmented reality technology is for the most part in a mature enough state to support workable technical solutions. Thus, the challenge is **to ensure good user experience and fulfil user expectations, and to develop technical features that promote these goals.** Accordingly, in order to solve the research problem and enhance AR towards mass market use at the consumer level, we need to consider the user experience.

In this work we discussed mainly features of the system and business ecosystem factors. However, there are a number of business factors (such as pricing, availability, etc.) affecting the adoption of the technology that should be studied and to be taken into account in development of AR services.

6. Conclusions and discussion

After extensively investigating several aspects of augmented reality and examining the key factors affecting the use of AR in consumer-level applications, it became clear that a successful technology has to be connected to the world around it. The users' needs, the use environment, and the business ecosystem all play a role in this success, and must be therefore each considered in all stages of the development.

Next, we will conclude the main outcomes of our research and discuss the research problem *how can user involvement be utilized in developing more effective AR experiences?*

6.1 How can user involvement be utilized in developing more effective AR experiences?

Based on our observations, we propose the following approach for bringing augmented reality technology into widely used consumer-level applications:

- **Identify the need for the technology** (see pages 47 and 90).
- **Select a potential business model** (see pages 91 and 96)
- **Identify user requirements with participatory & user-centred approaches** (see page 89)
- **Consider the special characteristics of the task** (see pages 65, 91 and 92)
- **Select a feasible subset of features and a business model**, not all user wishes are to be fulfilled (see page 92)
- **Develop a technical solution** (see Sections 4.2.3 and 4.3)
- **Evaluate and test the solution** (see pages 45 and 64)

Involving all actors in the development of a digital service in accordance with co-creation methods is valuable (see Section 5.1). The (co-)development is an iterative process, **and co-design is beneficial at all stages of the development process** from sketching the not-yet-existing service, to evaluation of the existing service (see Sections 3.3.2, 3.4.2 and 3.7.2).

Our guidelines for AR development are similar to general software and service development processes (see e.g. Benyon 2010, Maglio, Kieliszewski and Spohrer 2010). AR is by nature an impressive visualization method, and over the years many AR demonstrations have been based on a wow-effect. However, our contribution shows that this is not enough for common users; the solution should be helpful in a meaningful way to the user. While co-design is an established research method in other areas, it has been less applied to designing AR solutions. Our research proves that co-design and other user-centred methods serve the development of AR solutions as well.

Furthermore, our research shows that with adequate user-centred and participatory methods, one can determine the mindset and needs of the users and determine a service ecosystem that supports those needs through AR solutions (Papers I, II, III, and IV). This user-centred approach enabled us to identify bottlenecks in the adoption of AR technology and to focus on technical and algorithmic solutions to solve the most essential ones, thus bringing augmented reality closer towards commonplace use (Paper V, Paper VII).

We note that the best technical solution is always use case specific; while assembly instructions require non-photorealistic rendering, interior design visualization needs photorealistic rendering; some applications call for real-time video visualization, other times users prefer still images (cf. Paper V vs. Paper VI) Therefore, there is no unique “best (AR) technology” that can be applied across the board; instead, the special characteristics of each task should always be considered, along with the user experience and the use environment as a whole.

Another important aspect is that users are individuals with individual preferences. For example, different users prefer different interaction modalities (Paper V). In addition, different user groups have different needs and require different functionalities from the application (Paper III).

In order to bring AR into widely adopted consumer-level applications, the user’s needs, expectations and fears must be taken into account in the design process. The application has to be useful, and the user experience pleasing (Papers I, II, III, IV and V). In order to succeed in this, the technology must be developed (Paper VII) to support the crucial aspects of its use. In this way, the chasms in the technology adoption life cycle can be bridged.

A technology will be widely adopted only if users can clearly see the benefits of using it. However, even the most user-valued system will grind to a halt without someone to maintain it. In most cases this means that there must be some benefit to the service provider, i.e. a viable business ecosystem that supports the system’s existence (Paper III, Paper IV). Note that the currency of value is not always money, the benefits could be immaterial.

In our studies, the users sketched a non-existing service, evaluated an existing service, and ideated new ways of using such services. These studies verified users’ ability give valuable feedback at all stages of the design process. (Papers I, II and III.)

6.2 Enhancing augmented reality in interior design

Interior design is a prominent application area for augmented reality. An effective AR application makes planning interior designs easier and faster. Ideally it can make it feel as a leisure activity. AR also helps ordinary people to understand interior designs and room dimensions better. (Papers III, I, II and, e.g., page 60.) Authentic visualization of furniture and interior decoration has the potential to change interior decoration and the furniture retail business, where web sales share of markets is lower than in many other business areas. This could change radically if customers had the possibility to test furniture in their own home easily and reliably – an AR interior design application may enable this. AR interior design also has the potential to transform real estate marketing in a similar way (Siltanen et al. 2011).

Usually, new furniture is purchased for rooms that are already occupied with old furniture. Augmenting virtual elements in such a setting leads to virtual elements overlapping with the real ones to be replaced. This spoils the illusion of realism (see e.g. Figure 34, page 71). Our studies show that a lack of solutions to this common problem is preventing the use of AR in interior design (Papers III, I and II).

In paper VII, we propose a solution to overcome this problem: a workable diminished reality solution to remove existing furniture virtually. The implementation works in real time and produces realistic results for indoor scenes. It is also designed to be robust and suitable for ordinary users (Section 4.2.2). **The presented solution enhances AR interior design applications substantially and brings AR technology towards wider utilization**.

This work focused on early phases of application development: requirements specification and design. In addition, technical work i.e. application and algorithm development constitutes a significant part of the work. The evaluation and user tests at the end of the development cycle gained less attention, and the conducted tests were informal and included few users. In the future, one should carefully test and evaluate the results before the next development cycle. (The software development cycle is presented earlier in Figure 6, page 18).

Hassenzahl (2005; 2008) divides the factors affecting user experience in two types of attributes: *pragmatic* and *hedonic*. Pragmatic attributes enable *doing* something e.g. “making a phone call” and “finding a book in an online-bookstore”, whereas hedonic attributes enable *being* something e.g. “being competent”, “being related to others” and “being special”.

Pragmatic components are often what Kano (2001; Kano et al. 1984) called *One-dimensional quality elements* and *must-be quality elements* (see page 92). These are things that are necessary for the solution in the first place and things that destroy user experience if dysfunctional. In other words, pragmatic attributes facilitate the potential fulfilment of hedonic quality which leads to good user experience (Hassenzahl 2008).

Our work emphasized the design and early development phase of the digital solution. The development focused on pragmatic attributes; for example, without diminished functionality professional interior designers could not use the application at all.

Our studies adduce that besides functionality and being able to perform tasks aesthetics and attractiveness (see e.g. page 44) are important for users as well. Emotional aspects such as aesthetic and attractiveness have a great influence on the success of products and services and to perceived user experience. People also find attractive things easier to use. (Norman 2002.) These findings should be considered carefully in the future development.

6.3 Future directions in augmented reality

The AR field is in a state of change. Its enabling technologies (e.g. tracking) have reached sufficient maturity to enable AR to be applied in real life situations – majority of people is fast becoming aware of AR and its possibilities.

Figure 56. Microsoft HoloLens device. (Image used with permission from Microsoft.)

In addition, hardware technology and devices are also evolving rapidly. New lightweight display devices supporting AR, such as the Microsoft HoloLens[27] see-through wearable display (Figure 56) and Innovega's iOptik[28] cybernetic contact lenses (Figure 57), have the potential to change the way people explore and interact with their environment.

[27] http://www.microsoft.com/microsoft-hololens/
[28] http://innovega-inc.com/index.php

Figure 57. AR contact lenses by Innovega. (Left image: Timothy Hogan.) Images courtesy of Innovega.

Brain–computer interfaces (BCI) allow users to interact and control digital systems by thought (He et al. 2013). For augmented reality, the brain–computer interface creates a totally new user interaction paradigm (Lenhardt and Ritter 2010).

Another technology trend that has impact on the AR field is the development of depth cameras. The price of depth cameras is dropping while their accuracy and reliability is improving. They are also getting smaller. Depth cameras offer an easy solution to a number of critical AR issues, such as modelling a room and its existing furniture. As depth cameras become integrated in common devices, such as tablet PCs, it can be expected that consumer-level AR applications will penetrate the market on a large scale. This may happen in the near future. In 2013, Apple[29] acquired PrimeSense[30], known for its depth camera technology used in Microsoft's Kinect[31] motion sensor. Already today, with an add-on depth sensor, such as Structure Sensor[32] by Occipital, an ordinary tablet (e.g. iPad) can be transformed into a 3D scanner and modelling tool (Figure 58).

[29] https://www.apple.com/
[30] http://en.wikipedia.org/wiki/PrimeSense
[31] http://www.microsoft.com/en-us/kinectforwindows/default.aspx and http://www.xbox.com/en-US/kinect
[32] http://structure.io/

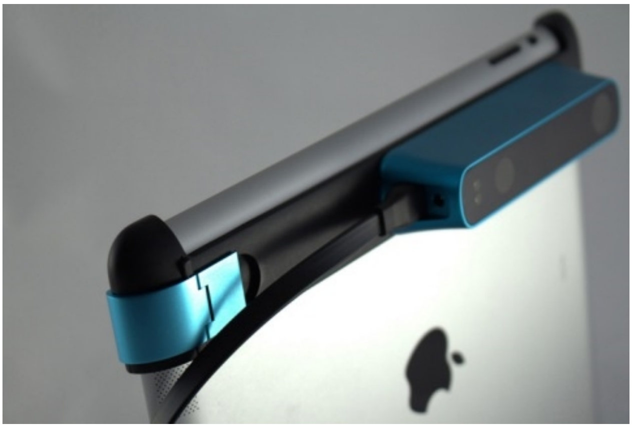


Figure 58. StructureSensor attached to an iPad. (Image source: StructureSensor.)

The vast collection of data on the Internet, aka *big data*, enables new approaches for combining virtual elements with reality (Huang, Hui and Peylo 2014). For example, the ready availability of 3D models makes it possible to resurrect objects from photos (Kholgade, Simon, Efros and Sheikh 2014)[33] (Figure 59). On the other hand, the *Internet of things* (IoT) – the concept of all possible objects and their information connected to the Internet (Li, Xu and Zhao 2014, Atzori, Iera and Morabito 2010) – creates a huge application area for location-aware AR visualizations (see e.g. Jara et al. 2014, Keil, Zoellner, Engelke, Wientapper and Schmitt 2013).

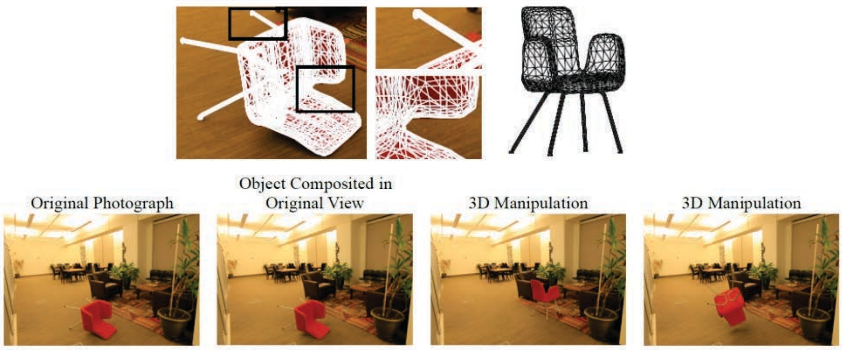


Figure 59. A 3D model is positioned and adjusted over an object in a photograph. Thereafter the object can be moved and rotated freely, as if it were 3D graphics. Images from (Kholgade et al. 2014).

[33] https://www.youtube.com/watch?v=bMeBvrG9Uyo

The importance of understanding the user is becoming ever more important as devices become increasingly attached – or even integrated – to the human body. The success of future AR services depends on how well developers can take into account human aspects and their influence on technology acceptance and user experience.

Mobile devices are becoming more and more personal and private. Close collaboration with users is therefore essential in order to design devices and services that the users will accept. Security and privacy issues also play a big role (Roesner, Kohno and Molnar 2014, Roesner, Kohno, Denning, Calo and Newell 2014).

In future, service-dominant logic is likely to have a significant role in the development of AR solutions; here, the customer and the expected service experience should be the focal point of the service development process (Helkkula, Kelleher and Pihlström 2012).

AR by its interactive nature enables playfulness and the gamification of serious services and supports formal and informal learning. The possibilities of AR are vast. In order to make beneficial AR solutions researchers must be able to reveal user needs – both existing and emerging ones – and develop technologies to fulfil those needs. We have demonstrated that this can be achieved by **developing augmented reality solutions through user involvement.**

6.4 Closure

Throughout this work we have referred to the ALVAR library and this doctoral thesis has been produced for Aalto University. These names have a double meaning; Alvar Aalto[34], the famous Finnish architect and designer (1898–1976), was a forerunner of modern functional design whose design approach was very close to the user-centred approach used in technology development. According to Aalto, in a successful design the user and purpose of use meet aesthetics. This is a valid guideline also for technology development. In Aalto's words (1928):

"Beauty is the harmony of purpose and form."

[34] http://www.alvaraalto.fi/aalto_arkkitehti_muotoilija.htm

Acknowledgements

The majority of this research was carried out within the following projects:

Adfeed project supported by Tekes[35] as part of the Next Media programme of the Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT aka DIGILE (former TIVIT)

Cloud Software project supported by Tekes as part of the Cloud Software programme of the Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT aka DIGILE

Muscle NoE, an EU FP6 ICT project (Multimedia Understanding through Computation Semantics and Learning, Network of Excellence)

ARARAT, a jointly-funded project supported by Tekes

The work was also funded partly through VTT internal projects.

[35] Tekes – the Finnish Funding Agency for Innovation, www.tekes.fi

References

ABATE, A.F., NARDUCCI, F. and RICCIARDI, S., 2013. Mixed Reality Environment for Mission Critical Systems Servicing and Repair. In: R. SHUMAKER, ed, Springer Berlin Heidelberg, pp. 201-210.

ABATE, A.F., NARDUCCI, F. and RICCIARDI, S., 2014. An Image Based Approach to Hand Occlusions in Mixed Reality Environments. In: R. SHUMAKER and S. LACKEY, eds., Springer International Publishing, pp. 319-328.

AILISTO, H., KORHONEN, I., TUOMISTO, T., SILTANEN, S., STRÖMMER, E., POHJANHEIMO, L., HYVÄKKÄ, J., VÄLKKYNEN, P., YLISAUKKO-OJA, A. and KERÄNEN, H., 2007. *Physical Browsing for Ambient Intelligence (PB-AmI).* Espoo, Finland: VTT.

AINASOJA, M., KAASINEN, E., VULLI, E., REUNANEN, E., HAUTALA, R., KULJU, M. and RYTÖÖVUORI, S., 2011. User involvement in service innovations – Four case studies, *Conference on Mass Customization, Personalization and Co-Creation* 2011.

AJANKI, A., BILLINGHURST, M., GAMPER, H., JÄRVENPÄÄ, T., KANDEMIR, M., KASKI, S., KOSKELA, M., KURIMO, M., LAAKSONEN, J., PUOLAMÄKI, KI, K., RUOKOLAINEN, T. and TOSSAVAINEN, T., 2011. An Augmented Reality Interface to Contextual Information. *Virtual Real.,* **15**(2-3), pp. 161-173.

ALAM, I. and PERRY, C., 2002. A customer-oriented new service development process. *Journal of Services Marketing,* **16**(6), pp. 515-534.

ALLENE, C. and PARAGIOS, N., 2006. Image Renaissance Using Discrete Optimization. *International Conference on Pattern Recognition,* **3**, pp. 631-634.

ATZORI, L., IERA, A. and MORABITO, G., 2010. The Internet of Things: A survey. *Computer Networks,* **54**(15), pp. 2787-2805.

AVERY, B., PIEKARSKI, W. and THOMAS, B.H., 2007. Visualizing Occluded Physical Objects in Unfamiliar Outdoor Augmented Reality Environments, *Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality* 2007, IEEE Computer Society, pp. 1-2.

AVERY, B., SANDOR, C. and THOMAS, B.H., 2009. Improving Spatial Perception for Augmented Reality X-Ray Vision, Virtual Reality Conference, 2 VR 2009. IEEE Computer Society, pp. 79-82.

AZPIAZU, J., SILTANEN, S., MULTANEN, P., MÄKIRANTA, A., BARRENA, N., DÍEZ, A., AGIRRE, J. and SMITH, T., 2011. Remote support for maintenance tasks by the use of Augmented Reality: the ManuVAR project, *9th Congress on Virtual Reality Applications, CARVI 2011*, November 10–11 2011.

AZUMA, R., 1997. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments 6*(4), pp. 355–385.

AZUMA, R., BAILLOT, Y., BEHRINGER, R., FEINER, S., JULIER, S. and MACINTYRE, B., 2001. Recent Advances in Augmented Reality. *IEEE Computer Graphics and Applications,* **21**(6), pp. 34-47.

BANE, R. and HÖLLERER, T., 2004. Interactive Tools for Virtual X-Ray Vision in Mobile Augmented Reality, *Proceedings of the 3rd IEEE/ACM International Symposium on Mixed and Augmented Reality* 2004, IEEE Computer Society, pp. 231-239.

BANO, M. and ZOWGHI, D., 2013. User Involvement in Software Development and System Success: A Systematic Literature Review, *Proceedings of the 17th International Conference on Evaluation and Assessment in Software Engineering* 2013, ACM, pp. 125-130.

BENYON, D., 2010. *Designing Interactive Systems: A comprehensive guide to HCI and interaction design.* 2nd edn. Ontario, Canada: Pearson Education Canada.

BERNARDOS, A.M. and CASAR, J.R., 2011. Analyzing business models for mobile augmented reality, *15th International Conference on Intelligence in Next Generation Networks (ICIN)*, 4–7 Oct. 2011, pp. 97–102.

BERTALMIO, M., SAPIRO, G., CASELLES, V. and BALLESTER, C., 2000. Image inpainting, *SIGGRAPH '00: Proceedings of the 27th annual conference on Computer graphics and interactive techniques* 2000, ACM Press/Addison-Wesley Publishing Co, pp. 417-424.

BICHLMEIER, C., HEINING, S.M., RUSTAEE, M. and NAVAB, N., 2007. Laparoscopic Virtual Mirror for Understanding Vessel Structure Evaluation Study by Twelve Surgeons. *IEEE/ACM International Symposium on Mixed and Augmented Reality,* 2007. ISMAR 2007. pp. 125–128.

BILLINGHURST, M. and DÜNSER, A., 2012. Augmented Reality in the Classroom. *Computer*, Vol. 45, No. 7, pp. 56–63.

BILLINGHURST, M., HAKKARAINEN, M. and WOODWARD, C., 2008. Augmented assembly using a mobile phone, *Proceedings of the 7th International Conference on Mobile and Ubiquitous Multimedia* 2008, ACM, pp. 84-87.

BILLINGHURST, M., KATO, H. and POUPYREV, I., 2001. The MagicBook – Moving Seamlessly between Reality and Virtuality. *IEEE Comput.Graph.Appl.,* **21**(3), pp. 6-8.

BIMBER, O. and RASKAR, R., 2005. Modern approaches to augmented reality, *SIGGRAPH '05: ACM SIGGRAPH 2005 Courses* 2005, ACM Press, 86 p.

BLESER, G., WUEST, H. and STRICKER, D., 2006. Online camera pose estimation in partially known and dynamic scenes. *IEEE/ACM International Symposium on Mixed and Augmented Reality, 2006, ISMAR 2006*, pp. 56-65.

BOHLEN, J.M. and BEAL, G.M., 1957. The Diffusion Process. Special Report No. 18, Agriculture Extension Service, Iowa State College, pp. 56-77.

BOLT, R.A., 1980. “Put-that-there”: Voice and gesture at the graphics interface, *Proceedings of the 7th annual conference on Computer graphics and interactive techniques* 1980, ACM, pp. 262-270.

BORNEMANN, F. and MÄRZ, T., 2007. Fast Image Inpainting Based on Coherence Transport. *J.Math.Imaging Vis.,* **28**(3), pp. 259-278.

BOUN VINH, L., KAKUTA, T., KAWAKAMI, R., OISHI, T. and IKEUCHI, K., 2010. Foreground and shadow occlusion handling for outdoor augmented reality, *9th IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2010*, pp. 109-118.

BRATH, R., PETERS, M. and SENIOR, R., 2005. Visualization for communication: The importance of aesthetic sizzle, *Proceedings of the Ninth International Conference on Information Visualisation* 2005, IEEE Computer Society, pp. 724-729.

BREEN, D.E., WHITAKER, R.T., ROSE, E. and TUCERYAN, M., 1996. Interactive Occlusion and Automatic Object Placement for Augmented Reality. *Computer Graphics Forum,* **15**(3), pp. 11-22.

BUI MINH, K., KIYOKAWA, K., MILLER, A., LA VIOLA, J.J., MASHITA, T. and TAKEMURA, H., 2014. The effectiveness of an AR-based context-aware assembly support system in object assembly, *Virtual Reality (VR), 2014 IEEE*, pp. 57-62.

BUTT, S.M. and WAN AHMAD, W.F., 2012. An Overview of Software Models with Regard to the Users Involvement. *International Journal of Computer Science Issues (IJCSI),* **9**(3), pp. 107-112.

BUXTON, W., 2007. *Sketching User Experiences: Getting the Design Right and the Right Design.* San Francisco, USA: Morgan Kaufmann.

CARBONELL, P., RODRÍGUEZ-ESCUDERO, A.I. and PUJARI, D., 2009. Customer Involvement in New Service Development: An Examination of Antecedents and Outcomes. *Journal of Product Innovation Management,* **26**(5), pp. 536-550.

CARMIGNIANI, J., FURHT, B., ANISETTI, M., CERAVOLO, P., DAMIANI, E. and IVKOVIC, M., 2011. Augmented Reality Technologies, Systems and Applications. *Multimedia Tools and Applications,* **51**(1), pp. 341-377.

CARROL, J.M., 2003. *Making Use: Scenario-Based Design of Human-Computer Interactions.* Cambridge, MA: The MIT Press.

CARUSO, G., RE, G.M., CARULLI, M. and BORDEGONI, M., 2014. Novel Augmented Reality system for Contract Design Sector. *Computer-Aided Design and Applications,* **11**(4), pp. 389-398.

CASCALES, A., LAGUNA, I., PEREZ-LOPEZ, D., PERONA, P. and CONTERO, M., 2013. An Experience on Natural Sciences Augmented Reality Contents for Preschoolers. In: R. SHUMAKER, ed, Berlin Heidelberg: Springer, pp. 103-112.

CASSIM, J. and DONG, H., 2003. Critical users in design innovation. In: J. CLARKSON, S. KEATES, R. COLEMAN and C. LEBBON, eds, London: Springer, pp. 532-553.

CAUDELL, T.P. and MIZELL, D.W., 1992. Augmented reality: an application of heads-up display technology to manual manufacturing processes, *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences,* 1992, Vol. 2, pp. 659-669.

CELOZZI, C., PARAVATI, G., SANNA, A. and LAMBERTI, F., 2010. A 6-DOF ARTag-based tracking system*, IEEE Transactions on Consumer Electronics,* **56**(1), pp. 203-210.

CHEN, J., GRANIER, X., LIN, N. and PENG, Q., 2010. On-line visualization of underground structures using context features, *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology* 2010, ACM, pp. 167-170.

CHONG, J.W.S., ONG, S.K., NEE, A.Y.C. and YOUCEF-YOUMI, K., 2009. Robot programming using augmented reality: An interactive method for planning collision-free paths. *Robotics and Computer-Integrated Manufacturing,* **25**(3), pp. 689-701.

CHRYSSOLOURIS, G., 2006. *Manufacturing Systems: Theory and Practice.* 2nd edition. New York: Springer.

CHRYSSOLOURIS, G., PAPAKOSTAS, N. and MAVRIKIOS, D., 2008. A perspective on manufacturing strategy: Produce more with less. *CIRP Journal of Manufacturing Science and Technology,* **1**(1), pp. 45-52.

COMPEAU, D.R. and HIGGINS, C.A., 1995. Application of Social Cognitive Theory to Training for Computer Skills. *Information Systems Research,* **6**(2), pp. 118–143.

CORBETT-DAVIES, S., DÜNSER, A., GREEN, R. and CLARK, A., 2013. An advanced interaction framework for augmented reality based exposure treatment, *Virtual Reality (VR), IEEE* 2013, pp. 19-22.

COSCO, F.I., GARRE, C., BRUNO, F., MUZZUPAPPA, M. and OTADUY, M.A., 2009. Augmented touch without visual obtrusion, *Proceedings of the 2009 8th IEEE International Symposium on Mixed and Augmented Reality* 2009, IEEE Computer Society, pp. 99-102.

CRIMINISI, A., PEREZ, P. and TOYAMA, K., 2003. Object removal by exemplar-based inpainting. *Proceedings of the 2003 IEEE Computer Society Conference on Computer Vision and Pattern Recognition,* **2**.

CRIMINISI, A., PEREZ, P. and TOYAMA, K., 2004. Region filling and object removal by exemplar-based image inpainting. *IEEE Transactions on Image Processing,* **13**(9), pp. 1200-1212.

DAMODARAN, L., 1996. User involvement in the systems design process – a practical guide for users. *Behaviour & Information Technology,* **15**(16), pp. 363-377.

DAVID, L., ENDLER, M., BARBOSA, S.D.J. and FILHO, J.V., 2011. Middleware Support for Context-Aware Mobile Applications with Adaptive Multimodal User Interfaces, *4th International Conference on Ubi-Media Computing (U-Media), 2011*, pp. 106-111.

DAVIS, F.D., 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, Vol. 13, No. 3, pp. 319–340.

DAVIS, F.D., 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly,* **13**(3), pp. 319-340.

DEY, A., CUNNINGHAM, A. and SANDOR, C., 2010. Evaluating depth perception of photorealistic mixed reality visualizations for occluded objects in outdoor environments, *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology* 2010, ACM, pp. 211-218.

DI SERIO, Á., IBÁÑEZ, M.B. and KLOOS, C.D., 2013. Impact of an augmented reality system on students' motivation for a visual art course. *Computers & Education,* **68**, pp. 586-596.

DIX, A., FINLAY, J.E., AUTHOR ABOWD, G.D. and BEALE, R., 2003. *Human-Computer Interaction.* 3rd edition. Upper Saddle River, NJ: Prentice Hall.

DONG, Z., ZHANG, G., JIA, J. and BAO, H., 2014. Efficient keyframe-based real-time camera tracking. *Computer Vision and Image Understanding,* **118**, pp. 97-110.

DÜNSER, A., STEINBÜGL, K., KAUFMANN, H. and GLÜCK, J., 2006. Virtual and Augmented Reality As Spatial Ability Training Tools, *Proceedings of the 7th ACM SIGCHI New Zealand Chapter's International Conference on Computer-human Interaction: Design Centered HCI* 2006, ACM, pp. 125-132.

EDVARDSSON, B., GUSTAFSSON, A. and ROOS, I., 2005. Service portraits in service research: a critical review. *International Journal of Service Industry Management,* **16**(1), pp. 107-121.

ENOMOTO, A. and SAITO, H., 2007. Diminished Reality using Multiple Handheld Cameras, *ACCV'07 Workshop on Multi-dimensional and Multi-view Image Processing* 2007, pp. 130-135.

EVANS, C., 2008. *Aliens and UFOs.* Carlton books Ltd.

FEDELI, L. and PIER, G.R., 2014. A Study on Real/Virtual Relationships Through a Mobile Augmented Reality Application. *International Journal of Digital Literacy and Digital Competence (IJDLDC),* **5**(1), pp. 10-20.

FENG, Z., DUH, H.B.-L. and BILLINGHURST, M., 2008. Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR, *7th*

IEEE/ACM International Symposium on Mixed and Augmented Reality, ISMAR 2008, pp. 193-202.

FENN, J., 2010-last update, 2010 Emerging Technologies Hype Cycle is Here – a blog writing [Homepage of Gartner], [Online]. Available: http://blogs.gartner.com/hypecyclebook/2010/09/07/2010-emerging-technologies-hype-cycle-is-here/ [November, 2010].

FIORENTINO, M., RADKOWSKI, R., UVA, A.E. and MONNO, G., 2012. Augmented Technical Drawings: A Novel Technique for Natural Interactive Visualization of Computer-Aided Design Models. *Journal of Computing and Information Science in Engineering,* **12**(2), pp. 024503-024503.

FONTANA, A. and FREY, J.H., 2005. The Interview. From Neutral Stance to Political Involvement. *Handbook of Qualitative Reserach.* 3rd edition. California, USA: Sage Publications, pp. 695-727.

FRANKE, N., VON HIPPEL, E. and SCHREIER, M., 2006. Finding Commercially Attractive User Innovations: A Test of Lead-User Theory. *Journal of Product Innovation Management,* **23**(4), pp. 301-315.

FROST & SULLIVAN, 2012. *Exploring the evolution of smartphone vendors.* Frost & Sullivan

FURMANSKI, C., AZUMA, R. and DAILY, M., 2002. Augmented-Reality Visualizations Guided by Cognition: Perceptual Heuristics for Combining Visible and Obscured Information, *Proceedings of the 1st International Symposium on Mixed and Augmented Reality* 2002, IEEE Computer Society, pp. 215.

GARTNER, 2014. *Gartner Research Methodologies Technology-related insights for your critical business decisions.* Gartner, Inc.

GEPHART, R., 2004. What is qualitative research and why it is important? *Academy of management journal,* **47**(4), pp. 454-462.

GIBSON, S., COOK, J. and HUBBOLD, R., 2003. Rapid shadow generation in real-world lighting environments, *Rendering techniques 2003* 2003, Eurographics symposium on rendering.

GREEN, R., 2010. *The Magic of Christmas by Santa.* Carlton Books Ltd.

GREENBAUM, J. and KYNG, M., eds, 1992. *Design at Work: Cooperative Design of Computer Systems.* Hillsdale, NJ, USA: L. Erlbaum Associates Inc.

GRÖNROOS, C. and GUMMESSON, E., 1985. The Nordic School of Services – An Introduction. In: GRÖNROOS, C. and GUMMESSON, E., eds, *Service Marketing – Nordic School Perspectives.* Stockholm, Sweden: University of Stockholm, pp. 6-11.

GRÖNROOS, C., 1978. A Service-Oriented Approach to Marketing of Services. *European Journal of Marketing,* **12**(8), pp. 588-601.

GRÖNROOS, C., 2006. Adopting a service logic for marketing. *Marketing Theory September,* **6**(3), pp. 317-333.

GRUBERT, J., LANGLOTZ, T. and GRASSET, R., 2011. *Augmented reality browser survey. Institute for Computer Graphics and Vision.* Technical Report Number 1101. Graz, Austria: University of Technology Graz.

GUMMESSON, E., 1991. Marketing Revisited: The Crucial Role of the Part-Time Marketer. *European Journal of Marketing,* **25**(1), pp. 60-67.

GYDENRYD, H., 1998. *How designers work: making sense of authentic Cognitive activity*. Lund, Sweden: Lund University.

HARTLEY, R. I. and ZISSERMAN, A., 2000. *Multiple View Geometry in Computer Vision.* Cambridge, UK*:* Cambridge University Press.

HASSENZAHL, M., 2005. The Thing and I: Understanding the Relationship Between User and Product. In: BLYTHE, M.A., OVERBEEKE, K., MONK, A.F. and WRIGHT, P.C., eds, Funology: From Usability to Enjoyment, Netherlands: Springer, pp. 31–42.

HASSENZAHL, M., 2008. User Experience (UX): Towards an Experiential Perspective on Product Quality, *Proceedings of the 20th International Conference of the Association Francophone D'Interaction Homme-Machine*. New York, NY, USA: ACM, 11 p.

HASSENZAHL, M. and TRACTINSKY, N., 2006. User experience – a research agenda. *Behaviour & Information Technology*, Vol. 25, No. 2, pp. 91–97.

HE, B., GAO, S., YUAN, H. and WOLPAW, J.R., 2013. Brain-Computer Interfaces. Neural Engineering, B. HE, ed, Springer US, pp. 87-151.

HE, Y. and LAI, K.K., 2012. Supply chain integration and service oriented transformation: Evidence from Chinese equipment manufacturers. *International Journal of Production Economics,* **135**(2), pp. 791-799.

HEISKANEN, HYVÖNEN, REPO and SAASTAMOINEN, 2007. *Käyttäjät tuotekehittäjinä.* Teknologiakatsaus 216/2007. Helsinki: Tekes. 56 p.

HELKKULA, A., KELLEHER, C. and PIHLSTRÖM, M., 2012. Characterizing Value as an Experience: Implications for Service Researchers and Managers. *Journal of Service Research,* **15**(1), pp. 59-75.

HENDERSON, S. and FEINER, S., 2011. Augmented reality in the psychomotor phase of a procedural task, *Proceedings of the 2011 10th IEEE International Symposium on Mixed and Augmented Reality* 2011, IEEE Computer Society, pp. 191-200.

HENDERSON, S. and FEINER, S., 2011. Exploring the Benefits of Augmented Reality Documentation for Maintenance and Repair. *IEEE Transactions on Visualization and Computer Graphics,* **17**(10), pp. 1355.

HENDERSON, S.J. and FEINER, S., 2009. Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret*, IEEE / ACM International Symposium on Mixed and Augmented Reality*, pp. 135-144.

HERLING, J. and BROLL, W., 2010. Advanced self-contained object removal for realizing real-time Diminished Reality in unconstrained environments, *2010 9th IEEE International Symposium on Mixed and Augmented Reality (ISMAR),* pp. 207-212.

HERLING, J. and BROLL, W., 2012. PixMix: A real-time approach to high-quality Diminished Reality, *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR),* pp. 141-150.

HIRSJÄRVI, S. and HURME, H., 2001. Tutkimushaastattelu. Teemahaastattelun teoria ja käytäntö. (In Finnish.) Helsinki, Finland: Yliopistopaino, pp. 34-48.

HONKAMAA, P., JÄPPINEN, J. and WOODWARD, C., 2007. A lightweight approach for augmented reality on camera phones using 2D images to simulate 3D, *Proceedings of the 6th international conference on Mobile and ubiquitous multimedia* 2007, ACM, pp. 155-159.

HONKAMAA, P., SILTANEN, S., JÄPPINEN, J., WOODWARD, C. and KORKALO, O., 2007. Interactive outdoor mobile augmentation using markerless tracking and GPS. Proceedings of Virtual Reality International Conference (VRIC), Laval, France, April 2007, pp. 285-288.

HU, S.J., KO, J., WEYAND, L., ELMARAGHY, H.A., LIEN, T.K., KOREN, Y., BLEY, H., CHRYSSOLOURIS, G., NASR, N. and SHPITALNI, M., 2011. Assembly system design and operations for product variety. *CIRP Annals – Manufacturing Technology,* **60**(2), pp. 715-733.

HUANG, Z., HUI, P. and PEYLO, C., 2014. When Augmented Reality Meets Big Data. CoRR, 8 p.

INAMI, M., KAWAKAMI, N. and TACHI, S., 2003. Optical Camouflage Using Retro-Reflective Projection Technology, *Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality* 2003, IEEE Computer Society, pp. 348.

IRANI, P. and WARE, C., 2003. Diagramming information structures using 3d perceptual primitives. *ACM Transactions on Computer-Human Interaction,* **10**(1), pp. 1-19.

IRAWATI, S., GREEN, S., BILLINGHURST, M., DÜNSER, A. and HEEDONG, K., 2006. An Evaluation of an Augmented Reality Multimodal Interface Using Speech and Paddle Gestures, *16th International Conference on Artificial Reality and Tel-existence (ICAT 2006)*. Springer. pp. 272-283.

IRIZARRY, J., GHEISARI, M., WILLIAMS, G. and WALKER, B.N., 2013. InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. *Automation in Construction,* **33**, pp. 11-23.

ISO FDIS 9241-210, 2009. *Ergonomics of human system interaction – Part 210: Human-centered design for interactive systems (formerly known as 13407).* Geneva, Switzerland: ISO.

JARA, A.J., LOPEZ, P., FERNANDEZ, D., CASTILLO, J.F., ZAMORA, M.A. and SKARMETA, A.F., 2014. Mobile Digcovery: Discovering and Interacting with the World Through the Internet of Things. *Personal Ubiquitous Computing,* **18**(2), pp. 323-338.

JARUSIRISAWAD, S., HOSOKAWA, T. and SAITO, H., 2010. Diminished reality using plane-sweep algorithm with weakly-calibrated cameras. *Progress in Informatics,* **7**, pp. 11-20.

JAWORSKI and KOHLI, 2006. *Co-creating the Voice of the Customer*. *The Service-Dominant Logic of Marketing: Dialog, Debate and Directions.* Armonk, New York: M.E. Sharpe.

JOHNSON, L., SMITH, R., LEVINE, J. and HAYWOOD, K., 2010. *2010 Horizon Report: K-12 Edition*. Austin, Texas, The New Media Consortium, 40 p.

JUN, J., YUE, Q. and QING, Z., 2010. An Extended Marker-Based Tracking System for Augmented Reality. *International Conference on Modeling, Simulation and Visualization Methods,* pp. 94-97.

KAASINEN, E., 2005. User acceptance of mobile services – value, ease of use, trust and ease of adoption. *VTT Publications 566*. Espoo, Finland: VTT.

KÄHKÖNEN, K., HYVÄKKÄ, J., PORKKA, J., SILTANEN, S. and WOODWARD, C., 2008. Integrating building product models with live video stream. 7th International Conference on Construction Applications of Virtual Reality (CONVR2007), Penn State University, USA, Oct 23-24, 2007, pp. 176-188.

KAHN, S., BOCKHOLT, U., KUIJPER, A. and FELLNER, D.W., 2013. Towards precise real-time 3D difference detection for industrial applications. *Computers in Industry,* **64**(9), pp. 1115-1128.

KALKOFEN, D., MENDEZ, E. and SCHMALSTIEG, D., 2007. Interactive Focus and Context Visualization for Augmented Reality, *Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality* 2007, IEEE Computer Society, pp. 1-10.

KANG, X., AZIZIAN, M., WILSON, E., WU, K., MARTIN, A.D., KANE, T., PETERS, C.A., CLEARY, K. and SHEKHAR, R., 2014. Stereoscopic augmented reality for laparoscopic surgery. *Surgical endoscopy,* **28**(7), pp. 2227-2235.

KANO, N., 2001. Life Cycle and Creation of Attractive Quality, *4th International QMOD Conference – Quality Management and Organizational Development.* Sweden, 18 p.

KANO, N., 2001. Life Cycle and Creation of Attractive Quality, *International QMOD Conference – Quality Management and Organizational Development* 2001, pp. 18-36.

KANO, N., SERAKU, N., TAKAHASHI, F. and TSUJI, S., 1984. Attractive Quality and Must-Be Quality. *The Journal of Quality,* **14**(2), pp. 39-48.

KARAPANOS, E., ZIMMERMAN, J., FORLIZZI, J. and MARTENS, J., 2009. User Experience over Time: An Initial Framework, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* 2009, ACM, pp. 729-738.

KASS, M., WITKIN, A. and TERZOPOULOS, D., 1988. Snakes: Active contour models. *International Journal of Computer Vision,* **1**(4), pp. 321-331.

KAWAI, N., SATO, T. and YOKOYA, N., 2014. From Image Inpainting to Diminished Reality. In: R. SHUMAKER and S. LACKEY, eds, Springer International Publishing, pp. 363-374.

KAWAI, N., YAMASAKI, M., SATO, T. and YOKOYA, N., 2012. AR marker hiding based on image inpainting and reflection of illumination changes, *IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2012*, pp. 293-294.

KEIL, J., ZOELLNER, M., ENGELKE, T., WIENTAPPER, F. and SCHMITT, M., 2013. Controlling and Filtering Information Density with Spatial Interaction Techniques via Handheld Augmented Reality. In: R. SHUMAKER, ed, Berlin Heidelberg: Springer, pp. 49-57.

KEIL, J., ZOLLNER, M., BECKER, M., WIENTAPPER, F., ENGELKE, T. and WUEST, H., 2011. The House of Olbrich – An Augmented Reality tour through architectural history, *2011 IEEE International Symposium On Mixed and Augmented Reality – Arts, Media, and Humanities (ISMAR-AMH)*, 26–29 Oct. 2011, pp. 15–18.

KELLEY, T. and LITTMAN, J., 2001. *The art of innovation: Lessons in creativity from Ideo, America's leading design firm.* New York: Doubleday.

KHOLGADE, N., SIMON, T., EFROS, A. and SHEIKH, Y., 2014. 3D Object Manipulation in a Single Photograph using Stock 3D Models. *ACM Transactions on Computer Graphics,* **33**(4), 12 p.

MIN-UK, K. and KYOUNGRO, Y., 2014. JPEG-AR Standard Enabling Augmented Marketing, 2014 International Conference on IT Convergence and Security (ICITCS), 28–30 Oct. 2014, pp. 1–2.

KLEIN, G. and MURRAY, D., 2007. Parallel Tracking and Mapping for Small AR Workspaces. *6th IEEE and ACM International Symposium on Mixed and Augmented Reality, ISMAR 2007*, pp. 225-234.

KOKARAM, A., 2002. Parametric texture synthesis for filling holes in pictures, *Image Processing on International Conference (ICIP)* 2002, pp. 325–328.

KORKALO, O., AITTALA, M. and SILTANEN, S., 2010. Light-Weight Marker Hiding For Augmented Reality, *The Ninth IEEE International Symbosium on Mixed and Augmented Reality*, October 13-16, 2010.

KOWALKOWSKI, C., 2010. What does a service-dominant logic really mean for manufacturing firms? *CIRP Journal of Manufacturing Science and Technology,* **3**(4), pp. 285-292.

KUJALA, S., 2003. User Involvement: A Review of the Benefits and Challenges. *Behaviour & Information Society,* **22**(1), pp. 1-16.

KURZ, D. and BENHIMANE, S., 2011. Gravity-Aware Handheld Augmented Reality, *Proceedings IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR2011)*, 26-29 October 2011, pp. 111-120.

KYMÄLÄINEN, T., 2014. *Science Fiction Prototypes as Design Outcome of Research – Reflecting ecological research approach and experience design for the Internet of Things.* Doctoral dissertation. Espoo, Finland: Aalto University.

LECHNER, M., 2013. ARML 2.0 in the context of existing AR data formats, 2013 6th Workshop on Software Engineering and Architectures for Realtime Interactive Systems (SEARIS), 17 March 2013, pp. 41–47.

LEE, D., LEE, S.G., KIM, W.M. and LEE, Y.J., 2010. Sphere-to-sphere collision estimation of virtual objects to arbitrarily-shaped real objects for augmented reality. *Electronics Letters,* **46**(13), pp. 915-916.

LEE, G.A., YANG, U., KIM, Y., JO, D., KIM, K., KIM, J.H. and CHOI, J.S., 2009. Freeze-Set-Go Interaction Method for Handheld Mobile Augmented Reality Environments, *Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology*. New York, NY, USA: ACM, 143 p.

LEE, I., 2009. Towards Wireless Augmented Reality A Review of its Enabling Technologies, *Proceedings of the 2009 International Symposium on Ubiquitous Virtual Reality* 2009, IEEE Computer Society, pp. 25-28.

LEHONG, H., FENN, J. and LEEB-DU TOIT, R., 2014. *Hype Cycle for Emerging Technologies 2014.* Gartner.

LEHTINEN, T., MÄKIJÄRVI, M. and INKERI, E., 2010. *Dibitassut ja kadonnut prinsessa.* (In Finnish.) Helsinki, Finland: Kustannusosakeyhtiö Paasilinna.

LENHARDT, A. and RITTER, H., 2010. An Augmented-Reality Based Brain-Computer Interface for Robot Control. In: K.W. WONG, B. MENDIS, U. SUMUDU and A. BOUZERDOUM, eds, Berlin Heidelberg: Springer, pp. 58-65.

LEPETIT, V. and BERGER, M.-o., 2001. An Intuitive Tool for Outlining Objects in Video Sequences: Applications to Augmented and Diminished Reality, *International Symposium of Mixed Reality* 2001.

LEU, M.C., ELMARAGHY, H.A., NEE, A.Y.C., ONG, S.K., LANZETTA, M., PUTZ, M., ZHU, W. and BERNARD, A., 2013. CAD model based virtual assembly simulation, planning and training. *CIRP Annals – Manufacturing Technology,* **62**(2), pp. 799-822.

LI, H., WANG, S., ZHANG, W. and WU, M., 2010. Image inpainting based on scene transform and color transfer. *Pattern Recogn. Lett.,* **31**(7), pp. 582-592.

LI, J., LI, Y., ZHANG, J., LI, D. WANG, L. and ZHANG, M., 2013. A touchable virtual screen interaction system with handheld Kinect camera, *2013 International Conference on Wireless Communications & Signal Processing (WCSP),* pp. 1-4.

LI, S., XU, L. and ZHAO, S., 2014. The internet of things: a survey. *Information Systems Frontiers,* pp. 1-17.

LIAO, T. and HUMPHREYS, L., 2014. Layar-ed places: Using mobile augmented reality to tactically reengage, reproduce, and reappropriate public space. *New Media & Society,* SAGE journals, 19 p.

LIVINGSTON, M.A., SWAN IV, J.E., GABBARD, J.L., HÖLLERER, T.H., HIX, D., JULIER, S.J., BAILLOT, Y. and BROWN, D., 2003. Resolving Multiple Occluded Layers in Augmented Reality, *Proceedings of the 2nd IEEE/ACM International*

Symposium on Mixed and Augmented Reality 2003, IEEE Computer Society, pp. 56–65.

MAGLIO, P.P., KIELISZEWSKI, C.A. and SPOHRER, J.C., eds, 2010. *Handbook of Service Science – Service Science: Research and Innovations in the Service Economy.* Berlin, Heidelberg: Springer.

MAGNUSSON, P.R., 2009. Exploring the Contributions of Involving Ordinary Users in Ideation of Technology-Based Services. *Journal of Product Innovation Management,* 26(5), pp. 578–593.

MAGUIRE, M., 2001. Methods to support human-centred design. *International Journal of Human-Computer Studies,* (55), pp. 587–634.

MAIDA, J., BOWEN, C. and PACE, J., 2007. Improving Robotic Operator Performance Using Augmented Reality, PROCEEDINGS of the HUMAN FACTORS AND ERGONOMICS SOCIETY 51st ANNUAL MEETING — 2007.pp. 1635–1639

MAKITA, K., 2014. Invited Paper: 3D Model-Based Camera Tracking Technology for Augmented Reality. *SID Symposium Digest of Technical Papers,* 45(1), pp. 873–876.

MANN, S., 2002. Mediated Reality with implementations for everyday life. MIT Press journal PRESENCE: Teleoperators and Virtual Environments. MIT Press.

MAO, J.-Y., VREDENBURG, K., SMITH, P.W. and CAREY, T., 2005. The state of user-centered design practice. *Communications of the ACM,* **38**(3), pp. 105-109.

MASH, R., 2010. *Dinosaurs Alive! (Augmented Reality Book).* Carlton Books Ltd.

MENOR, L.J., TATIKONDA, M.V. and SAMPSON, S.E., 2002. New service development: areas for exploitation and exploration. *Journal of Operations Management,* **20**(2), pp. 135-157.

MILGRAM, P., TAKEMURA, H., UTSUMI, A. and KISHINO, F., 1994. Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum, pp. 282-292.

MIT, 2007. 10 Emerging Technologies 2007.

MOFFET, P., 2010. *Fairyland Magic (Augmented Reality Book).* Carlton Books Ltd (7 Jun 2010).

MOHLER, J.L., 2001. Using interactive multimedia technologies to improve student understanding of spatially-dependent engineering concepts, *Proc. Int. Graphicon 2001 Conference on Computer Geometry and Graphics, Nyzhny* 2001, pp. 292-300.

MORGAN, D.L., 1997. *The Focus Group Guidebook.* Thousand Oaks, CA: Sage Publications Ltd.

MOSIELLO, G., KISELEV, A. and AMY LOUTF, A., 2013. Using Augmented Reality to Improve Usability of the User Interface for Driving a Telepresence Robot. Journal of Behavioral Robotics, Vol. 4, No. 3, pp. 174–181.

MURASE, K., OGI, T., SAITO, K., KOYAMA, T. and BIRU, K.S., 2008. Correct Occlusion Effect in the Optical See-through Immersive Augmented Reality Display System. 18th International Conference on Artificial Reality and Telexistence 2008, pp. 12–19.

NAIMARK, L. and FOXLIN, E., 2002. Circular Data Matrix Fiducial System and Robust Image Processing for a Wearable Vision-Inertial Self-Tracker, *ISMAR '02: Proceedings of the 1st International Symposium on Mixed and Augmented Reality* 2002, IEEE Computer Society, pp. 27.

NÄKKI, P., KOSKELA, K. and PIKKARAINEN, M., 2011. Practical model for userdriven innovation in agile software development, In: K. THOBEN, V. STICH and A. IMTIAZ, eds, *Proceedings of the 2011 17th International Conference on Concurrent Enterprising (ICE 2011)* 2011.

NENONEN, S. and STORBACKA, K., 2010. Business model design: conceptualizing networked value co-creation. *International Journal of Quality and Service Sciences,* **2**(1), pp. 43.

NORMAN, D.A., 2002. Emotion and design: Attractive things work better. *Interactions Magazine*, Vol. ix, No. 4, pp. 36–42.

NORMAN, D.A., 1998. *The Invisible Computer.* Cambridge, MA, USA: MIT Press.

NOVAK-MARCINCIN, J., BARNA, J., JANAK, M. and NOVAKOVA-MARCINCINOVA, L., 2013. Augmented Reality Aided Manufacturing. *Procedia Computer Science,* **25**, pp. 23-31.

OKSMAN, V., KULJU, M. and SILTANEN, S., 2011. Designing Creative Tools: A User-Centered Approach to Ambient Home Design, November 16 2011.

OKSMAN, V., SILTANEN, S., VÄÄTÄNEN, A., KULJU, M. and KYMÄLÄINEN, T., 2011. *Concept evaluation – User Experience.* WP 1 ADFEED 3.1.1.2. Next Media – Tivit programme.

OLSSON, T., LAGERSTAM, E., KÄRKKÄINEN, T. and VÄÄNÄNEN-VAINIO-MATTILA, K., 2011. Expected user experience of mobile augmented reality services: a user study in the context of shopping centres. *Personal and Ubiquitous Computing,* **17**(2), pp. 287-304.

PATRICK, M., MARCUS, T. and KLINKER, G., 2009. Augmented Reality for teaching spatial relations, *CD-ROM Proceedings from the Conference of the International Journal of Arts and Sciences,* 2009.

PELLOM, B. and HACIOGLU, K., 2003. Recent Improvements in the CU SONIC ASR System for Noisy Speech: The SPINE Task, *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP),* April 2003, pp. 1-9.

PELLOM, B., 2001. *SONIC: The University of Colorado Continuous Speech Recognizer.* Technical Report TR-CSLR-2001-01. University of Colorado.

PILET, J., LEPETIT, V. and FUA, P., 2007. Retexturing in the Presence of Complex Illumination and Occlusions, *Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality* 2007, IEEE Computer Society, pp. 1-8.

PINTO SEPPÄ, I., PORKKA, J., VALLI, S., SILTANEN, S., LEHTINEN, E. and TEERIMO, S., 2007. *Dwelling Renovation Studio. Interactive tool for private residences renovation service.* Research report No VTTR0145807. Espoo: VTT.

PRAHALAD, C.K. and RAMASWAMY, V., 2000. Co-opting customer experience. *Harvard Business Review,* **78**, pp. 79-87.

RANKOHI, S. and WAUGH, L., 2013. Review and analysis of augmented reality literature for construction industry. *Visualization in Engineering,* **1**(1), pp. 9.

REITMAYR, G. and DRUMMOND, T.W., 2007. *Initialisation for Visual Tracking in Urban Environments. 6th IEEE and ACM International Symposium on Mixed and Augmented Reality,* ISMAR 2007, pp. 161–172.

ROESNER, F., KOHNO, T. and MOLNAR, D., 2014. Security and Privacy for Augmented Reality Systems. *Communications of the ACM,* **57**(4), pp. 88-96.

ROESNER, F., KOHNO, T., DENNING, T., CALO, R. and NEWELL, B.C., 2014. Augmented Reality: Hard Problems of Law and Policy, *ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct Publication* 2014, ACM, pp. 1283-1288.

ROGERS, E., 2003. *Diffusion of Innovation.* 5th Edition. New York, USA: The Free Press.

ROSTEN, E., PORTER, R. and DRUMMOND, T., 2010. Faster and Better: A Machine Learning Approach to Corner Detection. *IEEE Transactions on Pattern Analysis and Machine Intelligence,* **32**, pp. 105-119.

SÄÄSKI, J., SALONEN, T., HAKKARAINEN, M., SILTANEN, S., WOODWARD, C. and LEMPIÄINEN, J., 2008. Integration of Design and Assembly Using Augmented Reality. In: RATCHEV, S. KOELEMEIJER, S. eds, *Micro-Assembly Technologies and Applications.* Springer Boston, pp. 395–404.

SÄÄSKI, J., SALONEN, T., SILTANEN, S., HAKKARAINEN, M. and WOODWARD, C., 2007. Augmented reality based technologies for supporting assembly work, In: ZUPANÈIÈ, B. KARBA, R. and BLAŽIÈ, S. eds, *Proceedings of the 6th EUROSIM Congress on Modelling and Simulation*, 9–13 Sept. 2007.

SALONEN, T., SÄÄSKI, J., HAKKARAINEN, M., KANNETIS, T., PERAKAKIS, M., SILTANEN, S., POTAMIANOS, A., KORKALO, O. and WOODWARD, C., 2007. Demonstration of assembly work using augmented reality, *Proceedings of the 6th ACM international conference on Image and video retrieval* 2007, ACM, pp. 120-123.

SALONEN, T., SÄÄSKI, J., WOODWARD, C., KORKALO, O., MARSTIO, I. and RAINIO, K., 2009. Data Pipeline From CAD to AR Based Assembly Instructions. *ASME Conference Proceedings,* **2009**(43376), pp. 165-168.

SALVADOR, F., CHANDRASEKARAN, A. and SOHAIL, T., 2014. Product configuration, ambidexterity and firm performance in the context of industrial equipment manufacturing. *Journal of Operations Management,* **32**(4), pp. 138-153.

SANDERS, E.B.-N. and STAPPERS, P.J., 2008. Co-creation and the new landscapes of design. *CoDesign,* **4**(1), pp. 5-18.

SANDOR, C., CUNNINGHAM, A., DEY, A. and MATTILA, V.-V., 2010. An Augmented Reality X-Ray system based on visual saliency, *9th IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2010*, pp. 27-36.

SANDOR, C., DEY, A., CUNNINGHAM, A., BARBIER, S., ECK, U., URQUHART, D., MARNER, M.R., JARVIS, G. and SANG RHEE, 2010. Egocentric space-distorting visualizations for rapid environment exploration in mobile mixed reality, *Virtual Reality Conference (VR), 2010 IEEE*, pp. 47-50.

SANTOS, P., STORK, A., BUAES, A., PEREIRA, C. and JORGE, J., 2010. A real-time low-cost marker-based multiple camera tracking solution for virtual reality applications. *Journal of Real-Time Image Processing,* **5**(2), pp. 121-128.

SARASPÄÄ, H.W., 2014. *Personal communication.*

SAVIOJA, P., JÄRVINEN, P., KARHELA, T., SILTANEN, P. and WOODWARD, C., 2007. Developing a mobile, service-based augmented reality tool for modern maintenance work, *Proceedings of the 2nd international conference on Virtual reality* 2007, Springer-Verlag, pp. 554-563.

SCHALL, G., MENDEZ, E. and SCHMALSTIEG, D., 2008. Virtual redlining for civil engineering in real environments, *ISMAR 2008. 7th IEEE/ACM International Symposium on Mixed and Augmented Reality, 2008*, pp. 95-98.

SCHALL, G., MENDEZ, E., KRUIJFF, E., VEAS, E., JUNGHANNS, S., REITINGER, B. and SCHMALSTIEG, D., 2009. Handheld Augmented Reality for underground infrastructure visualization. *Personal Ubiquitous Comput.,* **13**(4), pp. 281-291.

SCHULER, D. and NAMIOKA, A., 1993. *Participatory Design: Principles and Practices.* Hillsdale, NJ, USA: L. Erlbaum Associates Inc.

SEN-CHING, S., CHEUNG, J.Z. and VENKATESH, M.V., 2006. Efficient Object-Based Video Inpainting, *IEEE International Conference on Image Processing, 2006*, pp. 705-708.

SEO, D.W. and LEE, J.Y., 2013. Direct hand touchable interactions in augmented reality environments for natural and intuitive user experiences. *Expert Systems with Applications,* **40**(9), pp. 3784-3793.

SHARP, H., ROGERS, Y. and PREECE, J., 2007. *Interaction Design: Beyond Human-Computer Interaction.* Second edition. Hoboken, NJ: John Wiley.

SHEKHAR, R., DANDEKAR, O., BHAT, V., PHILIP, M., LEI, P., GODINEZ, C., SUTTON, E., GEORGE, I., KAVIC, S., MEZRICH, R. and PARK, A., 2010. Live augmented reality: a new visualization method for laparoscopic surgery using continuous volumetric computed tomography. *Surgical endoscopy,* **24**(8), pp. 1976-1985.

SHEN, Y., ONG, S.K. and NEE, A.Y.C., 2010. Augmented reality for collaborative product design and development. *Design Studies*, Vol. 31, No. 2, pp. 118–145.

SHEPARD, D., 1968. A two-dimensional interpolation function for irregularly-spaced data, *ACM National Conference* 1968, pp. 517–524.

SHIRLEY, P., ASHIKHMIN, M. and MARSCHNER, S., 2009. *Fundamentals of Computer Graphics.* 3rd edn. Natick, MA, USA: A. K. Peters, Ltd.

SILTANEN, S. and AIKALA, M., 2012. Augmented reality enriches hybrid media, *Proceeding of the 16th International Academic MindTrek Conference 2012: "Envision Future Media Environments"*, 3–5 Oct. 2012, pp. 113-115.

SILTANEN, S. and HYVÄKKÄ, J., 2006. Implementing a Natural User Interface for Camera Phones Using Visual Tags, In: W. PIEKARSKI, ed, *Seventh Australasian User Interface Conference (AUIC2006); CRPIT* 2006, ACS, pp. 113-116.

SILTANEN, S., 2006. Texture generation over the marker area, *IEEE/ACM International Symposium on Mixed and Augmented Reality, ISMAR 2006*, Oct. 2006, pp. 253.

SILTANEN, S., 2011. Augmented Reality beyond the hype – what is it good for? (Keynote talk), *MUSCLE International Workshop on Computational Intelligence for Multimedia Understanding*, 13–15 December 2011.

SILTANEN, S., 2012. *Theory and applications of marker-based augmented reality.* VTT Science 3. Espoo, Finland: VTT.

SILTANEN, S., 2013. Augmented Reality creates the WOW effect in the Cloud. In: T. HUOMO, K. KARPPINEN and P. PUSSINEN, eds, *Value-driven business in the Cloud, VTT Research Highlights 9,* Espoo, Finland: VTT, pp. 80-81.

SILTANEN, S., HAKKARAINEN, M. and HONKAMAA, P., 2007. Automatic Marker Field Calibration, *VRIC – Virtual Reality International Conference*, 18–20 April 2007, pp. 261-267.

SILTANEN, S., SARASPÄÄ, H. and KARVONEN, J., 2014. [DEMO] A complete interior design solution with diminished reality, IEEE International Symposium on Mixed and Augmented Reality (ISMAR), Munich, Germany, September 10–12, 2014, pp. 371–372.

SILTANEN, S., SEISTO, A., MENSONEN, A. and WULFF, R., 2011. *WP1 AdFeed project, Deliverable 3.1.1.2 AUGMENTED REALITY IN ADVERTISING PROTOTYPE, AUGEMENTED REALITY IN REAL ESTATE MARKETING.* Espoo, Finland: TIVIT – Next Media.

SILTANEN, S., WOODWARD, C., VALLI, S., HONKAMAA, P. and RAUBER, A., 2008. User Interaction for Mobile Devices. In: P. MARAGOS, A. POTAMIANOS and P. GROS, eds, *Multimodal Processing and Interaction – Audio, Video, Text.* Springer.

SPENCE, I., 1990. Visual psychophysics of simple graphical elements. *Journal of Experimental Psychology: Human Perception and Perfomance,* **4**(16), pp. 683-692.

STEEN, M., MANSCHOT, M. and KONING, N.D., 2011. Benefits of Co-design in Service Design Projects. *International Journal of Design,* **5**(2).

STONE, R., BISANTZ, A., LLINAS, J. and PAQUET, V., 2008. Improving Tele-robotic Landmine Detection through Augmented Reality Devices, 2008, pp. 206-210.

SU, H., KANG, B. and TANG, X., 2008. Research and Implementation of Hybrid Tracking Techniques in Augmented Museum Tour System. Technologies for E-Learning and Digital Entertainment, Lecture Notes in Computer Science Volume 5093, 2008, pp. 636-643.

SUTHERLAND, I.E., 1965. The Ultimate Display, *Proceedings of the IFIP Congress* 1965, pp. 506-508.

SUTHERLAND, I. E., 1968. A Head-mounted Three Dimensional Display, *Proceedings of the December 9–11, 1968, Fall Joint Computer Conference, Part I* 1968, ACM, pp. 757-764.

SUWA, M., GERO, J.S. and PUERCELL, T.A., 1998. The Roles of Sketches in Early Conceptual Design Process, *Twentieth Annual Meeting of Cognitive Science Society* 1998, Madison.

SWAIN, M.J. and BALLARD, D.H., 1991. Color indexing. *Int.J.Comput.Vision,* **7**(1), pp. 11-32.

SWAN, J.E. and GABBARD, J.L., 2005. Survey of user-based experimentation in augmented reality, *Proceedings of 1st International Conference on Virtual Reality*, pp. 1–9.

SZELISKI, R., 2010. *Computer Vision: Algorithms and Applications.* New York: Springer-Verlag.

TELEA, A., 2004. An Image Inpainting Technique Based on the Fast Marching Method. *Journal of Graphics Tools,* **9**(1), pp. 23-34.

TING, H., CHEN, S., LIU, J. and TANG, X., 2007. Image inpainting by global structure and texture propagation, *Proceedings of the 15th international conference on Multimedia* 2007, ACM, pp. 517-520.

TOHIDI, M., BUXTON, W., BAECKER, R. and SELLEN, A., 2006. User Sketches: A Quick, Inexpensive, and Effective way to Elicit More reflective User Feedback, *Proceedings of NordiCHI 2006*, pp. 105-114.

VÄÄNÄNEN-VAINIO-MATTILA, K., OKSMAN, V. and VAINIO, T., 2007. Exploring the User Experience Factors in Designing Successful Mobile Internet Services for Business Use, *Workshop of Mobile Internet User Experience, Mobile HCI 2007*, September 9th, 2007.

VÄLKKYNEN, P., SILTANEN, S., VÄÄTÄNEN, A., OKSMAN, V., HONKAMAA, P. and YLIKAUPPILA, M., 2013. Developing Mixed Reality Tools to Support Citizen Participation in Urban Planning, In: M. BEHRENS, N. MEMAROVIC, M. TRAUNMUELLER, G. RUDKIN & A. FATAH GEN. SCHIECK, eds, *EXS 2.0 Exploring Urban Space in the Web 2.0 Era*, June 2013.

VAN KREVELEN, D.W.F. and POELMAN, R., 2010. A Survey of Augmented Reality Technologies, Applications and Limitations. *The International Journal of Virtual Reality,* **9**(2), pp. 1-20.

VANDERHEIDEN, G., 2002. Fundamental Principles and Priority Setting for Universal Usability, *Conference on Universal Usability* 2002, pp. 32-38.

VARGO, S., LUSCH, R. and AKAKA, M., 2010. Advancing Service Science with Service-Dominant Logic: Clarifications and Conceptual Development. In: P. MAGLIO, C. KIELISZEWSKI and J. SPOHRER, eds, *Handbook of Service Science.* Springer, pp. 133-156.

VARGO, S.L. and LUSCH, R.F., 2004. Evolving to a New Dominant Logic for Marketing. *Journal of Marketing,* **68**(1), pp. 1-17.

VARGO, S.L. and LUSCH, R.F., 2008. Service-Dominant Logic: Continuing the Evolution. *Journal of the Academy of Marketing Science,* **36**, pp. 1-10.

VARGO, S.L. and LUSCH, R.F., 2014. *Service-Dominant Logic Premises, Perspectives, Possibilities.* Cambridge, UK: Cambridge University Press.

VENKATESH, V. and DAVIS, F.D., 2000. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science,* **46**(2), pp. 186-204.

VENTÄ-OLKKONEN, L., POSTI, M., KOSKENRANTA, O. and HÄKKILÄ, J., 2012. User Expectations of Mobile Mixed Reality Service Content, *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*. New York, NY, USA: ACM, Article nro 52, pp. 1-2

VON HIPPEL, E., 1986. Lead users: A source of novel product concepts. *Management Science,* **32**(7), pp. 791-805.

VON HIPPEL, E., 2001. PERSPECTIVE: User toolkits for innovation. *Journal of Product Innovation Management,* **18**(4), pp. 247-257.

VON HIPPEL, E., 2005. *Democratizing innovation.* Cambridge, US: MIT Press.

WANG, X., 2009. Augmented Reality in Architecture and Design: Potentials and Challenges for Application. *International Journal of Architectural Computing,* **7**(2), pp. 309-326.

WANG, Z., 2008. Image Affine Inpainting, *Proceedings of the 5th international conference on Image Analysis and Recognition* 2008, Springer-Verlag, pp. 1061-1070.

WOODWARD, C., HAKKARAINEN, M., KORKALO, O., KANTONEN, T., AITTALA, M., RAINIO, K. and KAHKONEN, K., 2010. MIXED REALITY FOR MOBILE CONSTRUCTION SITE, VISUALIZATION AND COMMUNICATION, In: MAKANAE, YABUKI and KASHIYAMA, eds., *CONVR 2010, Proceedings of the 10th International Conference on Construction Applications of Virtual Reality*, November 4–5, 2010.

WOODWARD, C., KUULA, T., HONKAMAA, P., HAKKARAINEN, M. and KEMPPI, P., 2014. Implementation and evaluation of a mobile augmented reality system for building maintenance. In: DAWOOD, N. and ALKASS, S. eds, *Proceedings of the 14th International Conference on Construction Applications of Virtual Reality*, 16–18, November 2014. Sharjah: UAE.

WOODWARD, C., LAHTI J., RÖNKKÖ, J., HONKAMAA, P., HAKKARAINEN, M., JÄPPINEN, J., RAINIO, K., SILTANEN, S. and HYVÄKKÄ, J., 2007. Virtual and augmented reality in the Digitalo building project. *International Journal of Design Sciences and Technology,* **14**(1), pp. 23-40.

WOODWARD, C., LAHTI, J., RÖNKKÖ, J., HONKAMAA, P., HAKKARAINEN, M., SILTANEN, S. and HYVÄKKÄ, J., 2007. Case Digitalo — A range of virtual and augmented reality solutions in construction application, *Proceedings of 24th CIB W78 Conference* 2007, pp. 26–29.

YAMAUCHI, H., HABER, J. and SEIDEL, H., 2003. Image Restoration using Multiresolution Texture Synthesis and Image Inpainting. *Computer Graphics International Conference.* IEEE. pp. 120–125.

YOON, T. and JUNG, K., 2009. Fast 3D Collision Detection Algorithm using 2D Intersection Area. International Scholarly and Scientific Research & Innovation 3(12), 2009, pp. 639–642.

ZHUWEN, L., YUXI, W., JIAMING, G., LOONG-FAH, C. and ZHOU, S.Z., 2013. Diminished reality using appearance and 3D geometry of internet photo collections, *IEEE International Symposium on Mixed and Augmented Reality (ISMAR), 2013*, pp. 11-19.

ZOKAI, S., ESTEVE, J., GENC, Y. and NAVAB, N., 2003. Multiview Paraperspective Projection Model for Diminished Reality, *Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality* 2003, IEEE Computer Society, pp. 217.

ZÖLLNER, M., BECKER, M. and KEIL, J., 2010. Snapshot augmented reality – augmented photography. In: ARTUSI, A., ed, *Proceedings of VAST 2010, 11th International Symposium on Virtual Reality, Archaeology and Cultural Heritage*, 21–24th September 2010, Paris, France. Goslar: Eurographics Association, pp. 53–56.

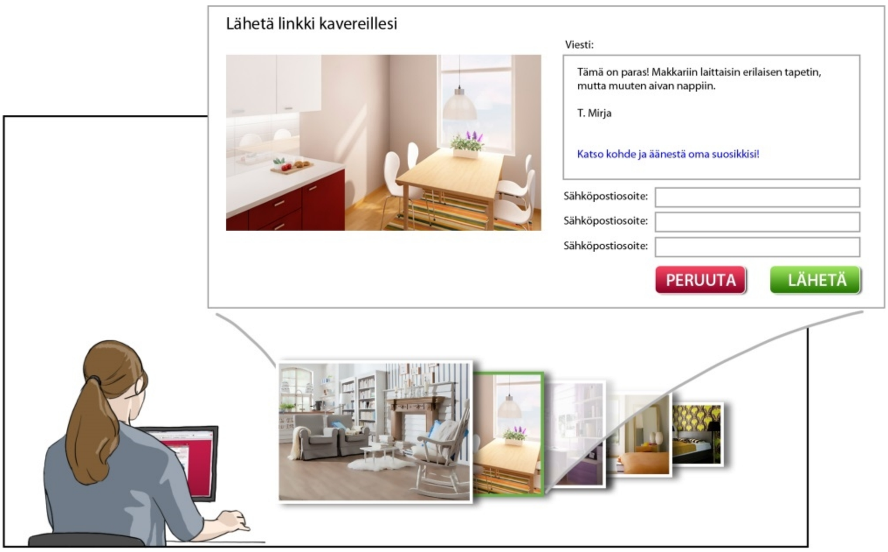
Appendix A: AR use scenarios

Scenario 1: A young couple is looking for a starter home

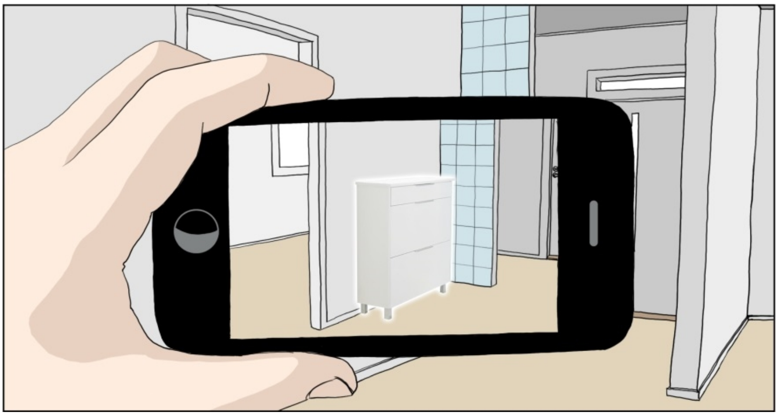
A couple in their mid-twenties is looking for a starter home from a popular city area. They wish to find a nice two or three bedroom apartment. They both have their own studio apartments with their own furniture. The challenge is to fit in all the dearest goods and furniture in the new apartment. Some of the old furniture has to be sold or put into storage, but at least the couple would like to keep a new sofa and the kitchen table. When choosing the right apartment, the couple has many discussions how they are going to fit in the furniture and what kind of new furniture they need to buy.

’3D interior design’ is new kind of portal, which presents modifiable virtual models of the apartments up for sale. The customers interested in buying the apartments can use 3D modelling to add virtual furniture in the apartments on sale. The user can try out new furniture from a ready selection or feed in the size of existing furniture. Users can also choose the colours and styles of the furniture from a number of different options. In this way, the young couple is able to make choices regarding furnishing of the new apartment and at the same time they got inspired to try out some new armchairs offered by the service.

The couple has already chosen two apartment options, which they are seriously considering. They have made 3D interior design plans for both of the apartments. They are able to save, view and edit their plans whenever they like. When the moment of the choice comes, they want also to hear their friends and parents opinions of the virtually furnished apartments. They place the virtual interior design plans in their Facebook pages. Their friends can comment their plans and one friend who is working in a home furnishing products shop makes some changes for the other plan. She adds a flexible wardrobe system in customizable functions in the small corridor of the apartment.



The friend’s proposal looks so good in the virtual plan that they want to study it even closer. They sign in for the service and download an AR application, which make it possible to see through the phone camera how the furniture looks in the real environment. They go to other apartment, target the phone camera in the corridor and decide the place and the size of the virtual wardrobe system. It fits perfectly in the corridor.



When the problem of the narrow corridor is solved, the couple decides to buy that apartment and orders the wardrobe system with a couple of other furniture found during the 3D design planning.

Scenario 2: A couple moving back to Finland is making interior design for their new home

A building company, a home furnishing store and some interior design houses are organizing a campaign to promote sales of new luxury apartments, because most of the brand new apartments are not yet sold. During the campaign discounts are offered from a wide range of interior design and furnishing products and materials. A couple living abroad notices the campaign immediately. They have been living abroad already over twenty years and are now considering to moving back to Finland. They want to make moving and starting their living in their new home as easy as possible. They have made some interior design plans with the service and sent them by e-mail to their friends and relatives in Finland.

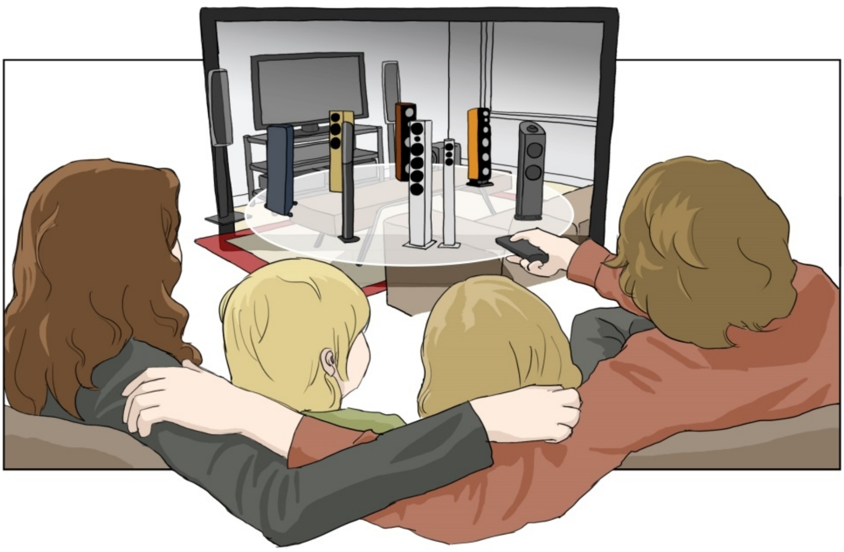
They have also sent their interior plans for the interior design houses which are participating in the campaign to ask some advice.

After some contacting the couple finds a common tone with one interior design company who also takes the responsibility of furniture assembly and transport.

Scenario 3: A family is making interior design for their new house with 3D television

A family has already bought a house which is going to be built on a new neighbourhood. With the virtual design program they consider different wallpapers for children's room as well as new furniture and home theatre.

The home theatre is going to be placed in the downstairs of the house and they need new elegant yet effective loudspeakers as well as some large acoustic boards for the wall. Some hifi-stores and home furnishing stores have offered their products for the service.



Scenario 4: Home decoration contest for bloggers

'3D interior design' service is organizing a contest regarding new homes. Five popular decoration bloggers are designing the interior of a similar three bedroom apartment in a new terraced house with the application. The bloggers have a wide range of different home furnishing products available for the virtual design to make styles they like. Several home furnishing products stores offer downloadable models for the service. During one week users can follow the proceeding of the five different plans, comment the solutions and share the links for their friends. The most enthusiastic users can make their own versions of the decoration plans and share them with their friends.

After a very tight and controversial contest the winner is announced: simple Scandinavian functionality beats romantic vintage country style. The winning blogger/interior designer gets money and a lot of publicity. The winner's interior designs are actually so popular that a couple of apartment buyers end up making their home furnishing according to the visions of the contest winner.

Finally the styles of the contest are saved in '3D interior design' –service. Many users are especially interested in 50's style of home furnishing products and they are able to see other related products in the service.

Scenario 5: AR renovating scenario

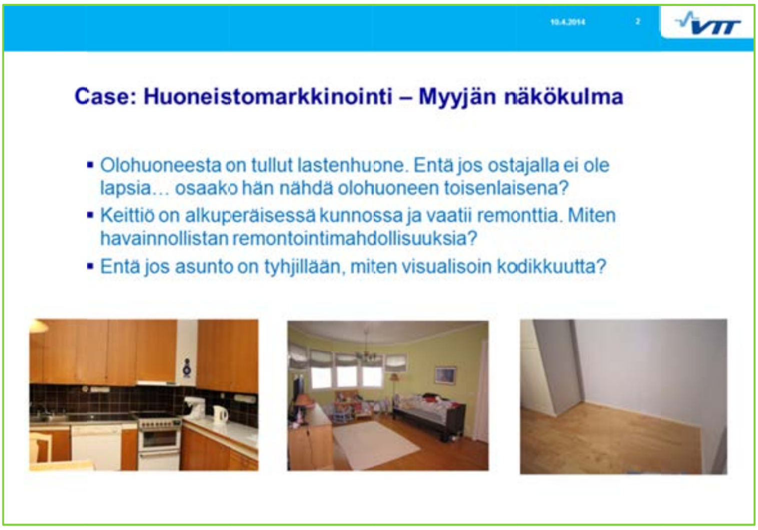
A family with two children is looking for a bigger apartment. They are looking for a new home that is not too expensive, and they are willing to do some decoration. They find an apartment with nice floor plan. However, not pleased with all the materials and colours.

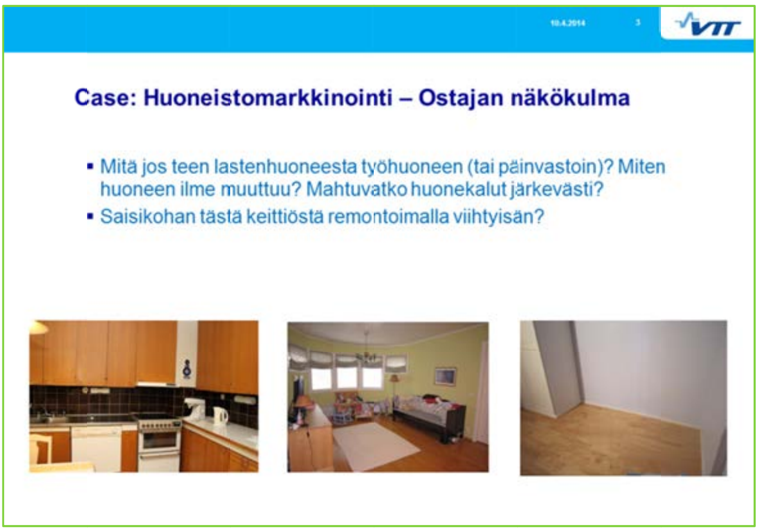
A real estate agent co-operates with interior decoration companies and furniture shops, and offers a web marketing campaign with virtual renovation and interior design functionalities. Sellers are aware that the colours are unfashionable and that the potential new owners probably want to repaint walls and change some of the surface materials. Therefore, the sellers have selected this particular real estate agent, as they know that it is easier to sell the apartment if the potential buyers are able to test their decoration plans.

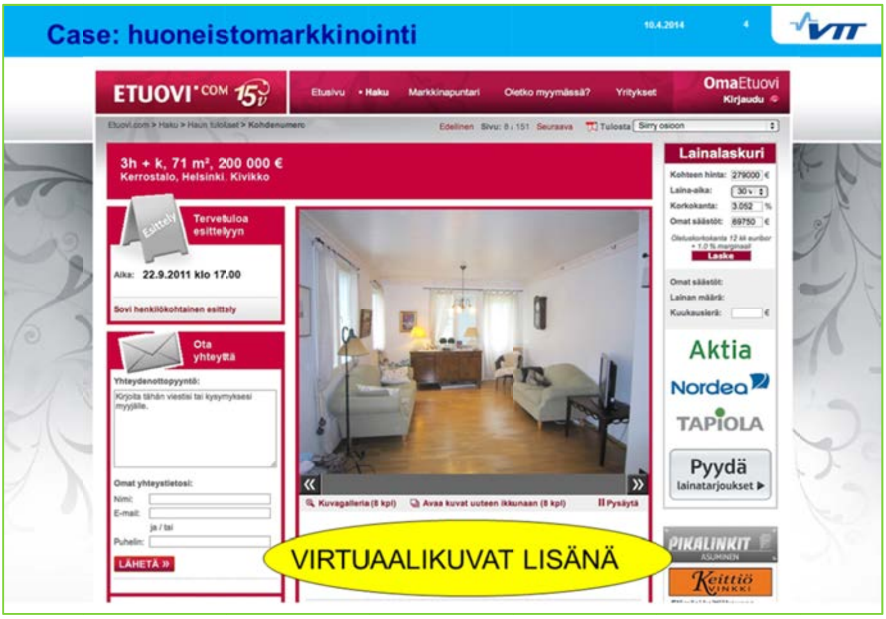
The family considering buying this apartment test their ideas. The mother paints the walls virtually and makes interior design plans to see if they can furnish it soundly. The father makes several measurements and tests different floor materials to get and gets a cost estimated for the renovation. The teenage daughter is thrilled as she is finally getting own room and is allowed to choose the colours, and some new piece of furniture, which she has been testing with interior design application.

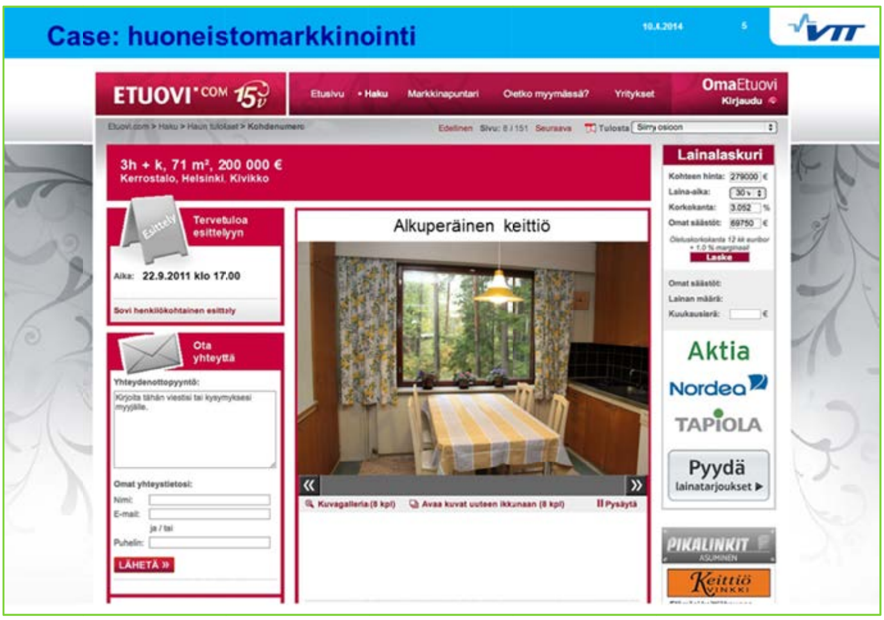
They can see that after relatively small redecoration, the apartment will be of their style, and the cost estimate for the required work is reasonable. So they have the courage of buying the apartment.

Appendix B: Illustrations used in innovation workshop






Case: huoneistomarkkinointi
10.4.2014
4
VTT
ETUOVI.COM 15v
Etusivu
Haku
Markkinapuntari
Oletko myymässä?
Yritykset
OmaEtuovi
Kirjaudu
3h + k, 71 m², 200 000 €
Kerrostalo, Helsinki, Kivikko
Tervetuloa esittelyyn
Aika: 22.9.2011 klo 17.00
Sovi henkilökohtainen esittely
Ota yhteyttä
Yhteydenottopyyntö:
Omat yhteystietosi:
LÄHETÄ »
Lainalaskuri
Aktia
Nordea
TAPIOLA
Pyydä lainatarjoukset
PIKALINKIT
Keittiö VINKKI
VIRTUAALIKUVAT LISÄNÄ


Case: huoneistomarkkinointi
10.4.2014
5
VTT
ETUOVI.COM 15v
Etusivu
Haku
Markkinapuntari
Oletko myymässä?
Yritykset
OmaEtuovi
Kirjaudu
3h + k, 71 m², 200 000 €
Kerrostalo, Helsinki, Kivikko
Tervetuloa esittelyyn
Aika: 22.9.2011 klo 17.00
Sovi henkilökohtainen esittely
Ota yhteyttä
Yhteydenottopyyntö:
Omat yhteystietosi:
LÄHETÄ »
Alkuperäinen keittiö
Lainalaskuri
Aktia
Nordea
TAPIOLA
Pyydä lainatarjoukset
PIKALINKIT
Keittiö VINKKI

Appendix C: ALVAR – A Library for Virtual and Augmented Reality

Business from technology

ALVAR – A Library for Virtual and Augmented Reality

ALVAR is a suite of products and libraries for creating virtual and augmented reality applications. ALVAR has been developed by the VTT Technical Research Center of Finland.

- ALVAR Library includes a high-level application programming interface (API) and several tools to create augmented reality applications with just a few lines of code. Low-level interfaces also make it possible to develop your own solutions using alternative approaches or completely new algorithms.
- ALVAR Studio offers high-level tools for creating AR applications for desktop and mobile platforms with just a few mouse clicks.
- ALVAR Industrial Solutions are specific applications for industrial users, such as Architectural, Interior Design, and Publishing companies.

MAIN FEATURES

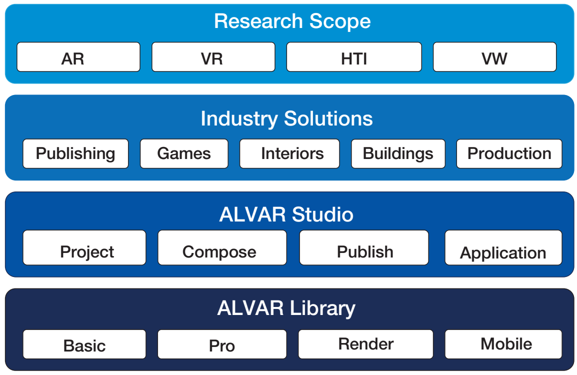
Marker based tracking
- Accurate marker pose estimation
- Two types of square matrix markers
- New marker types easy to add
- Recovering from occlusions
- Multiple markers for pose detection

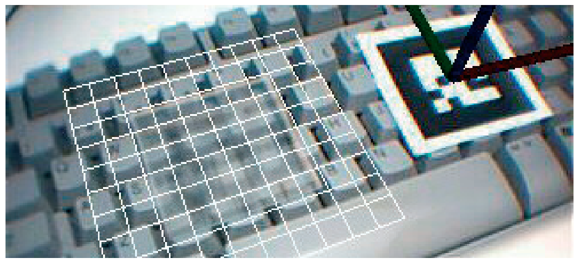
Markerless tracking
- Feature-based (tracking features from environment)
- Template-based (matching against predefined images or objects)

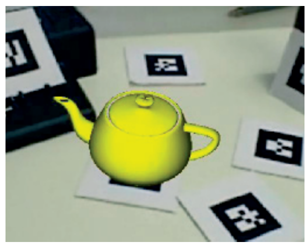
Rendering
- Materials, reflections, transparency
- Matching image quality to video, motion blur
- Lighting from real environment, soft shadows

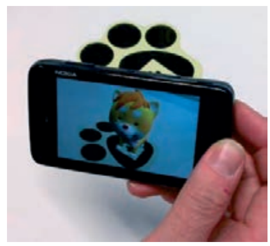
Other features
- Hiding markers from view
- Tools for camera calibration
- Several methods for tracking optical flow
- Distorting/undistorting points, projecting points
- Kalman framework and several other filters

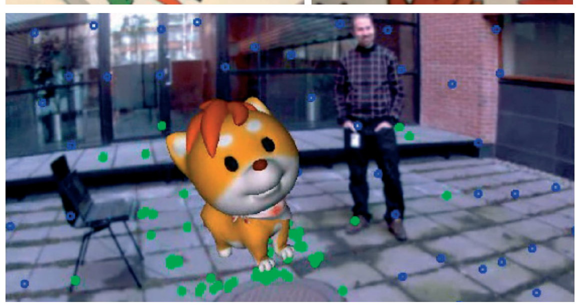
Platforms
- Windows, Linux, mobile phones











ALVAR Business Solutions

SOLUTIONS FOR PUBLISHING COMPANIES

Adds augmented information to printed publications (technical and educational books, cartoons, product catalogues etc.)

- Based on markers or real features in the printed material
- Augmented objects can support various interactions and narratives
- Allows photorealistic renderings, soft shadows, marker erasing etc.
- Supports both desktop and mobile use

SOLUTIONS FOR INTERIOR DESIGN

Provides augmented reality tools for furniture manufacturers, interior designers and home decoration purposes.

- Marker-based furniture positioning
- Supports multiple room images and multiple markers
- Live webcam, still image or mobile phone view
- Highly realistic designs with lighting, shadows and textures
- VividAR – Alvar-based web service for consumers by VividWorks

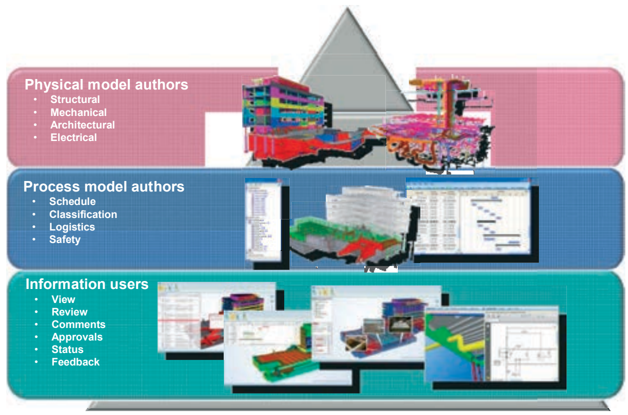
SOLUTIONS FOR BUILDING AND CONSTRUCTION

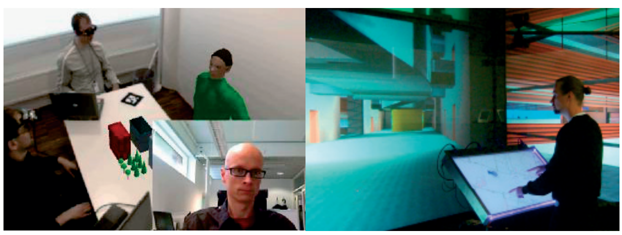
Seamless integration between architectural and BIM (building information model) systems:

- Compare project plans (4D BIM) with situation on-site
- Provide real-time mobile feedback from site to BIM-system
- Client-server system: Scalable even to mobile phones
- Construction site web cameras can be attached for public 4D demonstrations

OTHER SOLUTIONS AND PROJECTS:

- Entertainment and games
- Manufacturing, Assembly
- Mobile plant maintenance
- Mixed Reality video conferencing
- Multitouch surfaces, CAVE interaction





Application images by courtesy of Futurecode Oy, Aller Media Oy, VividWorks Oy, Pöyry plc. and Tekla plc.

Contact

Charles Woodward
Research Professor
Tel +358 20 722 5629
charles.woodward@vtt.fi

Harri Nurmi
Customer Manager
Tel +358 20 722 6199
harri.nurmi@vtt.fi

VTT Augmented Reality Team

www.vtt.fi/multimedia
alvar.info@vtt.fi

VTT TECHNICAL RESEARCH CENTRE OF FINLAND

Business from technology

PAPER I

Co-designing novel interior design service that utilizes augmented reality, a case study

In: Cipola-Ficarra, F. V. (Ed.) Advanced research and trends in new technologies, software, human-computer interaction, and communicability, IGI Global. Pp. 269–279.

Co-designing Novel Interior Design Service That Utilises Augmented Reality – a Case Study

Tiina Kymäläinen[1] and Sanni Siltanen[1]

[1]VTT Technical Research Centre of Finland, Tampere, Finland
tiina.kymalainen@vtt.fi

ABSTRACT. In this paper we describe a co-design process and implementation requirements of an interactive interior design service system. To gain design information for the system we studied two focus groups that were composed of designers, bloggers and serious amateurs in the field of interior design – the estimated critical users of the forthcoming service system. The framework for the co-design study was twofold. The design aim was to study users' innovation capability in the early phase of a complex process by utilising co-sketching as a means of obtaining a user model of the interactive system. The technological aim was to create interior design concepts that exploited augmented reality (AR), 3D models and user-generated content within the system framework. This paper reports the design process and results of the co-design sessions; furthermore, it presents requirements for the system, use cases utilising AR technology, plus consideration and evaluation of the AR functionalities.

Keywords: Interior design, human-centred design (HCD), front-end of innovation, focus group, sketching, co-design, augmented reality, virtual reality

1 Introduction

The case study was part of research that aimed at studying the use of new technologies and applications – social media services, augmented reality (AR) features and location awareness – in the field of advertising, and find new revenue models for media. This paper presents a case study which aimed at understanding the needs and requirements of the design service providers. Research was carried out by co-designing interactive user-centred interior design system concepts that utilised AR features. Co-design focus group sessions were arranged with interior designers and design bloggers – the anticipated critical users of the interior design system.

The participants of the study had taken part in a preliminary online survey, and were therefore all familiar with the background of the system concept. Participants received further information relating to the concept in the focus group sessions, first viewing scenarios that described possible ways of comprising interior 3D and AR services. Participants were then presented with some information from the preliminary online survey, including the key elements and materials thought by most respondents to be critical for the service. This was followed by a short presentation by the facilitators of the AR technology and existing AR applications.

In the co-design phase, the focus group participants co-sketched the system concepts. Sketching proved to be a practical method in this context, as the participants were able to produce dissectible results. Participants provided valuable design information during the discussions – in the form of use cases – concerning the promising ways of utilising AR technology in the service concept.

2 Chosen Key Technology: Augmented Reality

Augmented reality is defined as an interactive real-time system that combines real and virtual elements in 3D [1]. Virtual reality (VR) consists only of virtual elements. Diminished reality is a system where objects are removed from real environment, and mediated reality refers to a system where real environment is altered virtually [2]. Mixed reality (MR) is a concept that covers all possible combinations of real and virtual elements, from reality to total virtuality [3]. From the user's point of view the functionalities of a system are more important than the technology categorisation. “The basis in all the discussions was an AR system in which real images are augmented with virtual objects. However, in sessions the discussion was open to all forms of combination and alteration of real and virtual elements, including all the above-mentioned technologies –we used the term AR for simplicity, though.”

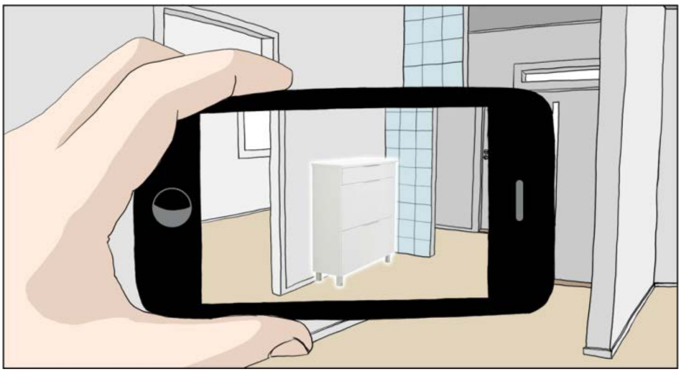


Fig. 1. With a mobile AR application the user can see virtual designs in real environment.

Augmented reality provides a practical visualisation method for purposes where there is a need to enhance the user's perception. Interior design, in particular, is an application field where the combination of real and virtual benefits the user [4]. Web-based AR applications – in not requiring installation or downloading – are consumer friendly and can be integrated with social media and web stores. Also, recent mobile devices are equipped with reasonable-sized displays and have network connection for accessing the Internet. Based on these facts, we selected a web-based AR interior design service as a starting point for the co-design discussions, and presumed that users could augment digital images and operate the system by using a PC or mobile device.

3 User-driven Innovation

3.1 Methods

The co-design process falls under the methodological frame of participatory design, which generally aims at democratising design so that the people to be affected by the systems should also be able to participate in and influence the design process [5]. Participants may be involved in the process by means such as focus groups, scenarios and early phase concept design [6–8]; methods which were adapted to this study. Focus group interview is an interview method in which a small group, with similar background, discusses the topics disseminated by the facilitator [6] – in this study, the similarity was the participants' interest in interior design. Because of their experience, the participants were seen as critical users [9] of the future service.

The co-design process was pragmatically conducted by utilising sketching as a co-design method, to provide means for users to produce design outcomes of a complex design service system [10]. The sketching method appeared to be a flexible way of prioritising design issues, and considered suitable for these particular focus group participants. The hypothesis was that sketches would offer support in obtaining a user model of the overall system [11].

3.2 Set-Up of the Co-design Session

The project group had identified a definition statement of the service concept for the focus groups: *'Novel web-based service concepts that exploited 3D and AR technologies, which may be used virtually when creating interior and renovation designs'*. The statement described the system and its core requirements in brief, and was meant to provide focus for the participants' concept ideas. Because the focus group participants were seen as service providers, the emphasis of the co-design session was on the service ecosystem of the concept.

At first, participants were encouraged to identify their role in the service system. It was decided mutually in the sessions that each participant would define her role as an ambiguous *designer*. Participants were then divided into pairs, and each pair encouraged to produce a sketch of the ecosystem in the form of a flowchart. The descriptions were expected to include: 1) all necessary stakeholders and elements of the system (products, services, technologies); 2) how all stakeholders and elements were connected to the ecosystem, and finally 3) which were the most important stakeholders and elements (using a tree-level scale).

The participants were encouraged to think about the application through discussed scenarios, and to exploit the information from the online survey and demonstrated applications. In the sketching phase, participants were provided with sketching tools: paper, pens, cardboards etc. Other materials, such as used e.g. in IDEO's tech box

[12]: colour schemes, pieces of wallpaper, images of furniture etc. were available for inspiration and reference purposes.

Following the sketching phase the focus group participants shared their ideas with others. After presentations, participants improved each other's ideas by paying attention to the application definition statement, scenarios, and, most importantly, personal interest.

3.3 Participants

The preliminary online survey data was collected from ordinary consumers (250 respondents) and serious interior design amateurs (36 respondents). The following two focus groups were composed of volunteers from the latter respondents, who were mostly interior designers or serious interior design amateurs: students and bloggers in the field of interior design. The two groups consisting of 3–4 participants, with 1–2 project participants in each group, and one evaluator leading the two-hour co-design session. The first focus group session was arranged in May 2011 at VTT Technical Research Centre of Finland, Espoo, and the second at Alma Mediapartners' facilities at Tampere, Finland. The interviewees were 27–49 years of age, all females.

4 Results

Participants provided detailed information on the qualities of the service during the introduction, while sketching the ecosystems and, finally, when considering the AR features for the service. The following presents the results of the discussions, the ecosystem sketches and the participants' AR use cases with detailed considerations.

4.1 Comments Relating to Scenarios

Pre-made scenarios were first presented, discussed and evaluated in the focus group sessions. The preference of serious interior designers for using very simple design tools in the presented cases was emphasised by the participants, who stressed that usability would be the crucial factor for their interest in using the system. Participants assumed that the real, accurate sizes of the apartment, rooms and furniture were the most critical individual features of the service system. Besides size, the most important qualities for the products, furniture and representative 3D models were stated to be style and colour. It was considered reasonable, however, for colour to be merely suggestive – e.g. fair, mid-dark or dark – to give an impression of the overall design. Participants thought that placing old, existing furniture in the design was even more important than buying new furniture through the service.

Fig. 2. Example of a Scenario: Interior design contest for design bloggers.

It was stated very clearly that a design process often begins by placing existing furniture – an ancestral cupboard or piano, for example – in place, with this piece or artefact defining the overall design plan. However, participants speculated that there might not be any party interested in providing such a service. If the service were to concentrate exclusively on selling new furniture, this would mean all major furniture providers having all their products available in the service system.

Concerning the sharing of design ideas through social media, participants remarked that if they were providing services themselves they would prefer to share their ideas with other interior designers, design enthusiastic people or customers. Designers suspected that general users of the service would also prefer at least semi-professional feedback on their design plans. The participants who were design amateurs were pleased by the idea of the scenario – presenting a home decoration contest (see Fig. 2) – perceiving that the special knowledge and expertise of interior designers and design amateurs could be fully utilised through the contest. Sharing design plans with a wider audience, or with friends and family, were seen as irrelevant.

4.2 Comments Relating to Example AR Applications

Participants subsequently saw three example applications that were benchmarked by the research group. The applications provided 3D and AR functionalities for creating interior designs. Participants were given an oral description of the benefits that were the criteria for selecting these specific applications.

Fig. 3. An interior application that utilised AR technology by VividWorks Ltd.

Participants provided detailed evaluation of the presented applications. The most important statements related to the visual appearances: the aesthetics. Participants emphasised that the 3D environments and models needed to be attractive and realistic. The realism brought to interior scenes by the showing of lights and shadows and textures in detail, for example, would make them more convincing. It was also seen as advantageous to induce the user/designer to feel that decorating rooms and creating plans was "leisure activity" – that it was fun to spend time in this way and to explore the service. The design competitions for interior designers in the example applications seemed to lack purpose: there were too many of them with no reward. In addition, the most important priority was stated to be the overall costs of the products and services. The existing services, however, only showed prices for single articles.

4.3 Sketches of the Service Ecosystem

After the introduction phase, participants created system concepts in pairs and presented them to each other. Figure 4 presents an example of a concept made by one of the pairs. The pair explained that the ambiguous *designer* and the service tool were identical (as it is the designer who uses the tool). The first task was to feed the background information and facts into the system, e.g. the floor plans. The sketch contained a two-way arrow – at this point the information either exists or has to be created. The main service providers in the cooperation were interior decorating stores (for wallpapers, floor and wall materials) and furnishing companies. The existing furniture was equally important – *"the past life, which does not vanish when a new home comes along"*. Service providers were the second priority: the individual designers who offer their services, or could be accessed through the service. A third priority was logistics; those who put all the pieces together and provide complete light decoration services, for example. This was followed by accessories, e.g. lighting providers and art suppliers. The sketch also described the chronology of events.

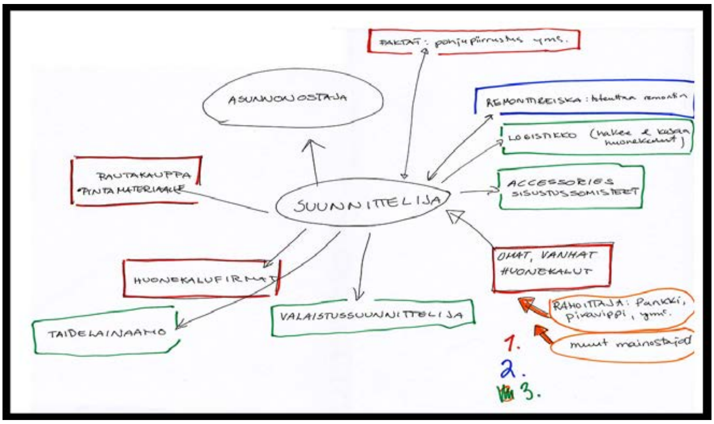


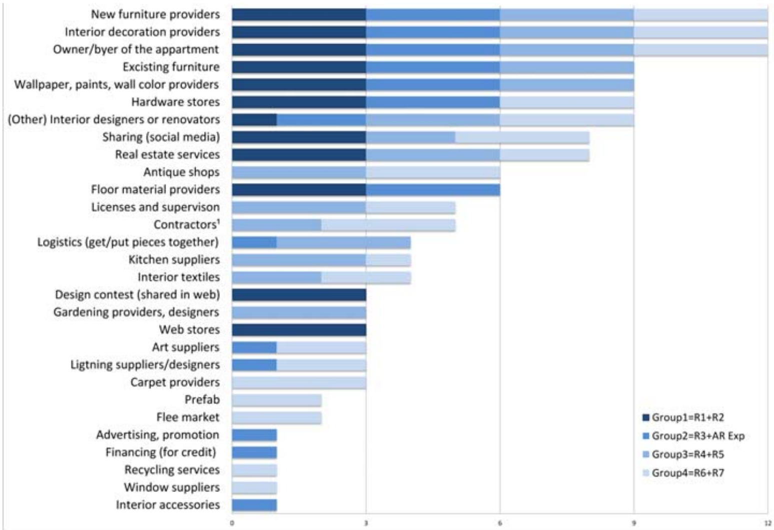
Fig. 4. Example of a sketched service ecosystem.

Table 1 presents the results of the service ecosystem sketches, and the conclusions of the co-sketching session. Participants were encouraged to determine the importance of the factors using a tree-level scale. For the most important factors, participants used numbering, a different colour, or a stronger line, and confirmed and explained the importance of the services after sketching the content. As the table shows, participants thought that the new furniture and interior decoration providers were key factors in the service. The participants perceived themselves in the co-design situation as designers, but while creating concepts all mentioned the importance of the customer relationship. Also, all mentioned the other designers – competitors or designers with different expertise. The participants highlighted some new providers to be included in the service: kitchen-, window- and carpet providers, antique shops, flea markets, art suppliers, gardening-, lighting- and 3D-model designers of existing furniture. From this viewpoint the service was seen as a cluster for smaller providers.

With a service dealing with novel ideas, participants emphasised that the price of furniture, material and accessories would constitute the essential feature of the concept. It was therefore considered important that the total cost of the new furniture and design alterations should be clearly visible. One group remarked that the customer could apply for a loan from a credit provider if it were possible to refer to an estimate provided by the service.

Because the information was qualitative there was some overlapping with the service providers presented in the table. Some participants, for example, mentioned hardware stores, but described them later as interior decoration providers, and placed both of them in their ecosystem sketches. There were also some conflicts relating to participants' statements of preference during the conversations, and how they were implemented in the ecosystem sketches. For example, all participants emphasised the importance of old, existing furniture in the service, but this nonetheless failed to receive the full amount of points in the analysis.

Table 1. Results of the service ecosystem sketches. If all pairs (groups 1–4) thought a service was most important, the service received 12 points. If only one mentioned it, and did not value it highly, the service received only one point.



[1] Contractors = e.g. HPAC-planning, electricity, masons

4.4 Ideas for Augmented Reality in Interior Design System

After sketching the service ecosystem concepts, the focus group participants thought more thoroughly about the AR features of the interior design service. Three topics were highlighted above others in the discussions: realistic lighting, number and variety of furniture models available (including 3D reconstruction of existing furniture), and search functionalities.

Based on their experience, participants emphasised how the lighting conditions affected the overall feeling and atmosphere of a space – and how difficult it was to explain for the customers. By using the AR technology, they saw an opportunity to visualise lighting effects: e.g. an ideal system would show the space in realistic lighting in the evening, morning, winter or summer, or according to the position of the windows. This would show the virtual apartment in a more realistic light: *"All dark corners during winter days, and harsh light during spring"*. Besides the ambient lighting, participants pointed out that it would also be useful to be able to model and visualise the lighting effects of different light sources e.g. to demonstrate the accurate size of selected spotlights.

Designers explained further that they constantly experienced situations in which they had no tools to communicate with the customers e.g. about the colours of the walls. One designer described such a situation: *"The effect of black walls are unimaginable for most customers, as white walls are still so common, but the* *atmosphere could really be altered by simply changing one wall to black."* This situation could be demonstrated quickly with on-site AR or VR technology.

The participants created use cases that could employ the AR technology, presenting a case in which a person was interested in a particular apartment. With this type of use the person could take pictures of the physical apartment and furnish it later virtually, at home, using the AR service.

The participants raised the issue of the visual quality of the design, which is highly important in interior design planning processes. The participants stressed the importance of the rendering quality of virtual objects: the application should be able to produce realistic materials and lighting effects on virtual objects. Participants stated that they would not engage AR features in the service unless the quality correlated sufficiently with the real environment.

Another important issue was that the availability of virtual models should not restrict the inspiration of a design. If the designer has e.g. an antique furniture model in mind, it should be possible to add it to the interior design plan or at least to represent it using an almost equivalent model. The same need applies to existing furniture; the user should be able to add virtual counterparts of the furniture easily into the design. This means that the 3D-object library should be large, and should contain generic objects whose colour, size and materials could easily be changed. Alternatively, designers should easily be able to create their own models e.g. based on images of an item of furniture. The service should also contain smaller objects, such as curtains, plants and flowers, paintings, posters and photo frames. Participants hoped for a sophisticated database search that enables search by colour, style and size. Typical situations were described as e.g. *"I need a chair of this size…"* or *"I want a reddish couch…"*.

5 Reflection: Technological Feasibility Concerning AR

Concerning the remarks on the AR functionalities, it was said that virtual lights and shadows affect not only the visual quality perceived by the user, but also the realism of the augmentation. In other words, virtual objects seem to hang in the air if they are not attached to the floor with virtual shadows. Virtual lighting, similar to real lighting, embeds the virtual furniture as part of the environment. It is also possible to adjust virtual lights easily, according to real light sources, with user interaction in interior design application [13].

Photorealistic rendering, i.e. the production of photo-like 3D graphics, is computationally demanding, similarly in applications where live video feed is augmented. However, still images are well suited to interior design applications [13], and computation time is therefore not an issue. It is possible to measure the real lighting conditions of the environment, adapt the virtual object to it, and produce adaptive photorealistic AR [14].

The participants expressed a need for a large object library that supports creativity, together with sophisticated search functionalities. The challenge of a model library lies in economics: how to create a business model that supports the creation and sharing of 3D models. We may assume that if an interior design service has a sufficient number of users, the creation of a large number of 3D models would be viable.

6 Conclusion

Since the focus group participants' expertise was high, they were able to create several new, aesthetic ideas for the interior design system concepts. AR technology was mostly speculated upon by offering examples of existing AR features, yet the participants were able to provide valuable feedback: AR use cases, and the fact that the evaluations of the feasibilities were based on the experience of interior designers.

The sketching approach for empowering a co-design process proved to be a flexible and productive method of involving users in the innovation conception phase, and for perceiving a user model of an interactive design system. Table 1 – the results of the service ecosystem sketches – presents certain evidence that it is also conceivable to analyse users' models. Moreover, because of the ecosystem descriptions, the highlighted issues were discussed more thoroughly in the focus groups. In exploiting sketching as a means of involving users in the interaction design processes, the key finding was that during the co-design session the sketches remained in the custody of the participants: even if the conversation and new information led opinions and ideas along different courses, participants expressed their judgements by referring to their sketches.

After studying the most important requirements of the critical users for the AR technology, it can be said that most ideas could easily be implemented in an interior design service system. When it comes to participants' needs for modelling existing furniture, however, it may take some time before practical solutions are available; current solutions for 3D reconstruction (i.e. construction of a three-dimensional model of an object from several two-dimensional views) require too much involvement and knowledge from the user. Research is nevertheless moving towards rapid 3D reconstruction on mobile devices [14]. In future interior design services, the user is expected to scan the interior environment effortlessly with a mobile device, and even obtain modelling of an existing item of furniture.

Focus group user evaluations and co-design sessions provided adequately new information for further design and development of interactive interior design services that utilise AR technology. The focus group participants, whom we anticipated to be the critical users of the service, in turn described the users of the service as: interior designers, interior architects, various decorators, model creators, lighting consultants, electrical consultants, small or large furniture companies (or individuals), decoration- and renovation providers.

Fig 5. Focus group participants creating novel interior design service concepts.

Acknowledgments. The research study was carried out within the Adfeed project which is supported by TEKES as part of the next Media programme of TIVIT (Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT). Minni Kanerva provided the illustrations for Figures 1–2.

References

1. Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. and MacIntyre, B. Recent Advances in Augmented Reality. IEEE Computer Graphics and Applications, Vol. 21, No. 6, pp. 34-47 (2001)
2. Mann, S. Mediated Reality with implementations for everyday life. Presence Connect, MIT Press journal PRESENCE: Teleoperators and Virtual EnvironmentsPresence (2002)
3. Milgram, P., Takemura, H., Utsumi, A. and Kishino, F. Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum. In Proceedings of the SPIE Conference on Telemanipulator and Telepresence Technologies, pp. 282-292 (1994)
4. Siltanen S. Theory and applications of marker-based augmented reality. VTT Science 3. Espoo. Finland, in Press (2012)
5. Schuler, D. and Namioka, A. Participatory Design: Principles and Practices, Lawrence Erlbaum Associates, Inc., Hillsdale, New Jersey (1993)
6. Morgan, D.L. The Focus Group Guidebook, Sage Publications Ltd. (1998)
7. Carroll, J.M. Making Use: Scenario-Based Design of Human-Computer Interactions. MIT Press, MA, USA (2009)
8. Greenbaum, J. and Kyng, M. (eds) Design at Work: Cooperative Design of Computer Systems. Lawrence Erlbaum Associates, New Jersey, USA (1991)
9. Cassim, J. and Dong, H. 'Critical users in design innovation'. In Clarkson, P.J., Coleman, R., Keates, S., and Lebbon, C. (eds.) Inclusive Design: Design for the Whole Population, Springer-Verlag, London. pp. 532-553 (2003)
10. Buxton, W. Sketching User Experiences: Getting the Design Right and the Right Design. Morgan Kaufmann, San Francisco, USA (2007)
11. Kymäläinen, T. in Saariluoma, P. (ed.), Kujala, T., Kuuva, S., Kymäläinen, T., Leikas, J., Liikkanen, L. and Oulasvirta, A. Ihminen ja teknologia - Hyvän vuorovaikutuksen

suunnittelu, Teknologiateollisuus, Helsinki, Finland (in Finnish). Human and Technology (2010)
12. Kelley, T., and Littman, J. The Art of Innovation: Lessons in Creativity from Ideo, America's Leading Design Firm. Doubleday, New York (2001)
13. Siltanen, S. and Woodward, C. Augmented Interiors with Digital Camera Images. Piekarski, W. (ed.) In proc. Seventh Australasian User Interface Conference (AUIC2006); CRPIT. ACS. Vol. 50: 33 (2006)
14. Aittala, M. Inverse lighting and photorealistic rendering for augmented reality. The Visual Computer, Vol. 26, No. 6, pp. 669-678 (2010)
15. Hartl, A., Gruber, L., Arth, C., Hauswiesner, S. and Schmalstieg, D. Rapid reconstruction of small objects on mobile phones. Computer Vision and Pattern Recognition Workshops, IEEE Computer Society Conference, Colorado Springs CO, USA, pp. 20-27 (2011)

PAPER II

User-created interior design service concepts, interfaces and outlines for augmented reality

In: Cipola-Ficarra, F. V. (Ed.) Emerging software for interactive interfaces, database, computer graphics and animation: pixels and the new excellence in communicability, cloud computing and augmented reality. Blue Herons. Pp. 28–47.

User-created Interior Design Service Concepts, Interfaces and Outlines for Augmented Reality

Tiina Kymäläinen* and Sanni Siltanen*

*VTT Technical Research Centre of Finland

{tiina.kymalainen,sanni.siltanen}@vtt.fi
http://www.vtt.fi/research/ict/

ABSTRACT. In this paper we describe a design process and implementation requirements of an interactive interior design service system. To gain design requirements for the system we studied two focus groups that were composed of designers, bloggers and serious amateurs in the field of interior design – the estimated critical users of the forthcoming service. The framework for the co-design study was twofold. The design aim was to study users' innovation capability in the early phase of a complex process by utilizing co-sketching as a means of obtaining user model of the interactive system. The technological aim was to create interior design concepts that exploited augmented reality (AR), 3D models and user-preferred content within the system framework. This paper reports the design process and results of the co-design sessions; furthermore, it presents requirements for the system and several interface descriptions and use cases utilizing AR technology, plus consideration and evaluation of the AR functionalities.

Keywords: Design, interior design, computer-aided design, human-centred design (HCD), focus group, sketching, interfaces, augmented reality (AR), virtual reality (VR)

1 Introduction

The study presented in this article was part of research that aimed at studying the use of new technologies and applications – social media services, augmented reality (AR) features and location awareness – in the field of advertising, and find new revenue models for media. This paper presents series of case studies, which aimed at understanding the needs and requirements of the interior design service providers. Research was carried out by co-designing interactive user-centred interior design systems and interface concepts that utilized AR features. Co-design focus group sessions were arranged with interior designers and design bloggers – the anticipated critical users of the interior design system.

Before the co-design studies, the participants had taken part in a preliminary online survey, and were therefore familiar with the background of the system concept. Participants received further information relating to the concept in the focus group sessions, first viewing scenarios that described possible ways of comprising interior 3D and AR services. Participants were then presented with some information from the preliminary online survey, followed by presentation of the AR technology and existing AR applications. The participants evaluated the applications and considered the most useful features for the future service.

In the co-design phase, the focus group participants co-sketched the system concepts. Sketching proved to be a practical method in this context, as the participants were able to produce innovative, original and dissectible results. Participants provided also valuable design information during the discussions – mostly in the form of use cases – concerning the promising ways of utilizing AR technology in the service concept. Central outcome of this research was to provide a framework for co-sketching user concepts with critical users. This framework may be utilized when designing complex systems, e.g. new interfaces and services.

2 User-driven Innovation and Used Methods

The process of this study falls under the methodological frame of participatory design, which generally aims at democratizing design, for example so that the people who will be affected by the systems should also be able to participate in and influence the design process [1]. When user research is carried out in the front-end of development processes, user's role may broaden up from mere research subject that comments ideas to an active co-designer [2]. Participants may be involved in the process by means such as focus groups, scenarios and early phase concept design [3–5]; methods which were all adapted to this study. Focus group interview is an interview method in which a small group, with similar background, discusses the topics disseminated by the facilitator [3] – in this study, the similarity was the participants' interest in interior design. Because of their experience, the participants were seen as critical users [6] of the future service.

The co-design process was pragmatically conducted by utilizing sketching as a co-design method, to provide means for users to create design outcomes of a complex design service system [7]. The sketching method appeared to be a flexible way of prioritizing design issues, and considered suitable for these particular focus group participants. The hypothesis was that sketches would offer support in obtaining a user model of the overall system [8]. In previous studies sketching had verified to be an efficient, flexible way to quickly generate, develop and communicate design ideas [7].

3 Participants

A preliminary online survey, which preceded this study, data was collected from ordinary consumers (250 respondents) and interior design professionals and amateurs (36 respondents). The following two focus groups introduced in this study were composed of volunteers from the latter respondents, who were mostly interior designers or serious interior design amateurs: students and bloggers in the field of interior design. The two groups consisted 3–4 participants, with 1–2 project participants in each group, and one evaluator leading the two-hour co-design session. One of the participants (P1) was an AR expert participating to the research project. The first focus group session was arranged in May 2011 at VTT Technical Research Centre of Finland, Espoo, and the second at Alma Mediapartners' facilities at Tampere, Finland. The interviewees were 27–49 years of age, all females.

Fig. 1. Focus group participants creating novel interior design service concepts.

Table 1: Participants of the first focus group in Espoo

Participant*	Age	Interior design experience	Familiar with 3D design programs
R1	42	Interior design blogger, interior design student	No
R2	34	Interior design blogger, degree in interior textiles	Yes
R3	33	Interior design blogger	No
P1	39	AR expert	Yes

Table 2: Participants of the first focus group in Tampere

Participant*	Age	Interior design experience	Familiar with 3D design programs
R4	27	Interior design blogger	Yes
R5	35	Interior design student, self-employed interior designer (renovator)	Yes
R6	49	Interior design teacher (redecoration & renovation)	Yes
R7	42	Interior design student	Yes
P2	36	Brokerage service provider	Yes
P3	40	Brokerage service provider	Yes

*Participants: R=Raters composed of interior design experts, P=Project participants

4 Chosen Key Technology: Augmented Reality

Augmented reality is defined as an interactive real-time system that combines real and virtual elements in 3D [9]. Virtual reality (VR) consists only of virtual elements. Diminished reality is a system where objects are removed from real environment, and mediated reality refers to a system where real environment is altered virtually [10]. Augmented virtuality refers to a system were real element are inserted to virtual environment. Mixed reality (MR) is a concept that covers all possible combinations of real and virtual elements, from reality to total virtuality [11]. From the user’s point of view the functionalities of a system are more important than the technology categorization. The basis in all the discussions was an AR system in which real images are augmented with virtual objects. However, in the co-design sessions the discussion was open to all forms of combination and alteration of real and virtual elements, including all the above-mentioned technologies.

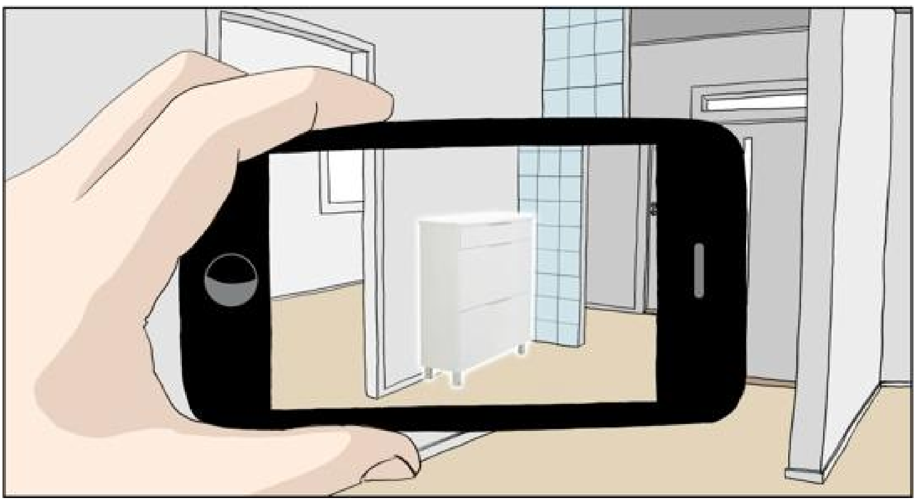


Fig. 2. With a mobile AR application the user can see virtual designs in real environment.

As the common level of understanding of these technologies is limited, not to mention the classification or demarcation between these branches of technology, we used only the term augmented reality for simplicity. The participants were encouraged to think about the functionalities of the system, and not the underlying technology for achieving it. For example, it was more important that they described a need for a possibility to change the colour of the wall, than to be able to describe such functionality to belong to mediated reality.

Augmented reality provides a practical visualization method for purposes where there is a need to enhance the user's perception. Interior design, in particular, is an application field where the combination of real and virtual benefits the user [12]. Web-based AR applications – in not requiring installation or downloading – are consumer friendly and can be integrated with social media and web stores. Also, recent mobile devices are equipped with reasonable-sized displays and have network connection for accessing the Internet. Besides, mobile operators provide affordable priced mobile subscriptions for data transmission. Based on these facts, we selected a web-based AR interior design service as a starting point for the co-design discussions, and presumed that users could augment digital images and operate the system by using a PC or a mobile device.

5 Pursuing User-driven Innovation Through Sketching

Before defining an effective framework for the study, we sought examples in which users had contributed to the development processes by using the means of sketches. As our more specific aim relates in how to design more complex systems, i.e. interaction- and service design concepts, the interest was also on how the multifaceted information should be delivered for users. The task for defining a framework for a study relates to the question of finding an optimal design process.

5.1 Studies Relating to Sketching

In many articles and literature references it is clearly pointed out that sketching provides means to access the thinking process [7, 12-15]. For example Gedenryd [14] claims that thinking and drawing are not at all separate cognitive processes – but thinking is simultaneous with the act of drawing. He explains further, that while thinking, designers transform the abstract principles requiring logical analysis into narrative or visual representations of the situation of use. Such representations are memorable, subjective and rich with details.

Bill Buxton has presented how creative and visual means may be exploited in user research in his seminal work "Sketching user experiences" [7]. He advocates the role of design in user research processes and claims that in those processes currently design is limited only to styling and usability. The act of sketching is more like problem setting and problem solving, as we already learned from the previous argument from Gedenryd. The most constructive part of Buxton's effort was that he provided characteristics of sketches. Sketches are e.g.: quick to make; they are timely, inexpensive; they have clear vocabulary and distinct gesture (they are open and free); they have minimal detail, and they suggest and explore rather than confirm, and the ambiguity of sketches provide new relations to arise. Buxton explains further that sketches are only by-products of the sketching activity. This leaves open the question how much it is possible to analyze users' sketches and whether or not there should be supplementary material alongside the sketches. He emphasizes yet that sketches are not prototypes; i.e. they might be used as complementary means for the front-end design processes, as one might interpret from his argument. Buxton concludes that it is worth the effort to engage users to the design processes, rather than trust merely in a group of designers, because "there are more than one futures".

In a throughout study of a touch-sensitive house climate control system Tohidi et al. [15] present an illuminating example how users' sketches are engaged in a usability study of an interactive device. The study employed 48 participants, which formed four separate user groups. In the initial phase of the study, participants gained a lot of information about the system. From the sketched material it was possible to analyze that the less participants reflected to the original design, the less successful they had previously evaluated it. But the most significant fining was that the multiple design condition sketches, provided by only one of the four groups, were much more rich in detail and there was more variation in them. The research group came to the conclusion that users' sketches provided more reflective feedback, and that sketching, as a method, was efficient, effective and satisfying way to conclude the study. This study acknowledges that it is worth to provide users with multifaceted, yet carefully selected, information.

In the study of Dorst et al. [16] provides empirical data on design processes from a set of protocol studies. Nine experienced industrial designers took part of the study by providing sketched material for further evaluation. The task was to create a concept for a 'litter disposal system' in a new Netherlands train. All the necessary information was prepared in advance in the design brief, which contained "natural amounts of vagueness and inconsistency". The designers were asked to provide sketches of the task and they were interviewed afterwards. Designs were then evaluated on the overall quality and on a variety of aspects. The scoring categories were: creativity, aesthetics, technical aspects, ergonomics and business aspects (in random order). In the last run-through, the reviewers were asked to give a total judgment of the concepts. This study showed how it was possible to analyze sketched concepts and apply quantitative methods for interpreting sketches. However, this method might not apply conclusively in any other design studies. In addition, this method required that experienced designers produce sketched concepts.

These studies provided evidence that sketching was a well-adapted method in the field of user research and sketching method might be applied for both interface design as well as service design. However, these studies do not consider sketching to be used as method for designing more complex or new domains; e.g. complex interaction applications and design services.

5.2 Defining the Structure For the Framework

George Pólya provides means to pursue the process in his widely quoted seminal work "How to solve a problem" [17]. According to him, at first, we must understand the problem. What was significant in his strategies for out study was that he also suggested that a diagram or picture might assist in understanding the initial problem. Then came the part of devising a plan, and he continued that this phase was also possible to exemplify by drawing the proposal. Then pursue went on by executing the plan, and after the process it was necessary that the plan is reviewed and extended.

Turkka Keinonen has illustrated four main concept design phases [18] that may be exploited in the co-design of more complex systems:

- Collation of information
- Interpretation of the information
- Description of the activity
- Description of the concept

These guidelines are meant for user-centred design processes that are conducted by a designer or a facilitator. In our study the facilitators of the co-design sessions are responsible of collation of information and partly interpretation of the information. It is left for the participants to find the description of the activities and finally delivering the concept.

For the overall process we may yet find most accurate process description by Ben Shneiderman [19]. According to Shneiderman, there are three levels of creativity: everyday, evolutionary and revolutionary. The creativity relating to the framework we are pursuing, is mainly concerned with evolutionary creativity. Shneiderman has proposed a process description under a title "Mega-creativity", which, according to him, means that more people are enabled to be more creative more of the time. He presents following set of tasks for Mega-creativity:

1. Searching and browsing digital libraries (the Web) and other resources
2. Visualizing data and the whole process to understand and discover relationships
3. Consulting with peers and mentors for intellectual and emotional support
4. Thinking by free association to make new combinations of ideas
5. Exploring Solutions – scenarios and simulation models
6. Composing artifacts and performances step by step
7. Reviewing and replaying session histories to support reflection
8. Disseminating results to gain recognition and add to the searchable resources.

For our study it was important that the participating users had only the most significant information about the content they were expected to illustrate. It was facilitators' responsibility to search for the meaningful information and make logical representations of the information. Consequently, facilitators were responsible of the first two tasks that Scneiderman presented in his framework. The third task was important, as in our case, this was the part in which the co-design participants could review, discuss and validate the information and confirm that they understand the design task appropriately. Sketching the concepts included the tasks 4-6. It was also important that other participants reviewed the sketches, which could be be refined and discussed upon. Disseminating the results is the final task for the research group.

5.3 Concluding Framework for Co-sketching User Concepts For New Interfaces and Services

Based on the literary findings we propose following framework for co-sketching user concepts for more complex and new domains, including system-, interaction- and service design. Steps of the framework are:

Research group:

- Collation of information about a specific context
- Specifying information meaningfully
- Providing description of the concept, presenting the information

Participants:

- Sketching the conceptual models (system/interface/service)
- Co-design: Collation of the information and brief interpretation
- Sketching with more specific objective (a specific part of system/interface/service)
- Co-design: Defining the criteria and interpretation of the user-driven information

Research group:

- Interpretation of the user-driven information
  - Analysis of the sketched material
  - Other relevant descriptions (use cases)
- New description of the concept

The framework is intended to cover the front-end of an innovation process. For a successful co-design process, the roles of each participant should be clarified implicitly. These set of tasks define the roles of the facilitators and the users. The designer’s role is most influential in the first and last design phases, which requires knowledge and thinking of a designer [20] when s/he facilitates the co-design sessions and interprets the results. The framework that we propose here differs from previous proposals in that it does not require laborious user involvement before the focus group session than e.g. the use of probes [21] does, and it does not have time-limited co-design phases such as e.g. the dialogue-labs method proposed by Lucero et al. [22] embraces. At the end of this article we refine the framework more carefully according to the findings of our case study.

6 Set-Up For the Introduction

After collating the information about the interior design service system and specifying that information, our research group came up with a well-defined description of the concept. The definition statement of the service concept for the focus groups was:

‘Novel web-based service concepts that exploited 3D and AR technologies, which may be used virtually when creating interior and renovation designs.’

The statement described the system and its core requirements in brief, and was meant to provide focus for the participants’ concept ideas. In addition with the concept definition participants were familiarized with the service in the introduction phase by presenting pre-made scenarios, benchmarked applications and some results of the preliminary online survey, which was collected from ordinary consumers.

6.1 Presented Scenarios

A widely adopted method exploited in our study was written and illustrated future scenarios. The presented scenarios were short, written descriptions of possible futures comprising interior 3D and AR design services and the use of technology with interior designers and their customers (see Fig. 3-5). Scenarios were used as a source of inspiration for focus group participants, because they introduced personas of hypothetical users with presumed needs, and encouraged to think about the service concept. As all participants had taken part to the online survey, they were familiar with the scenarios and the service concept. Three selected scenarios were: scenario 1.) Young couple is looking for first home; scenario 2.) Couple is moving back from abroad (and are making interior design for new home); and scenario 3.) Interior design contest for design bloggers.

Scenario 1. Young Couple is Looking For the First Home

A couple in their mid twenties is looking for a new home from a popular area. They wish to find a nice two-three-bedroom apartment. They both have their own smaller apartments with furniture. The challenge is to fit in all their dearest belongings to the new apartment. When choosing the appropriate apartment, the couple has many discussions to make how they are going to fit in the furniture and what kind of new furniture they need to buy.

Fig. 3**.** Young couple is looking for first home.

Scenario 2. Couple is Moving Back From Abroad

A construction company, a home furnishing store and some interior design stores are organizing a campaign to promote sales of new luxury apartments. During the campaign, discounts are offered from a wide range of interior design and furnishing products and materials. A Finnish couple living abroad notices the campaign. They have been living abroad over twenty years and are now considering to moving back. They want to things as easy as possible. The wife has made some interior design plans with the help od an interior designer and they have contacted various service providers with the help of the service.

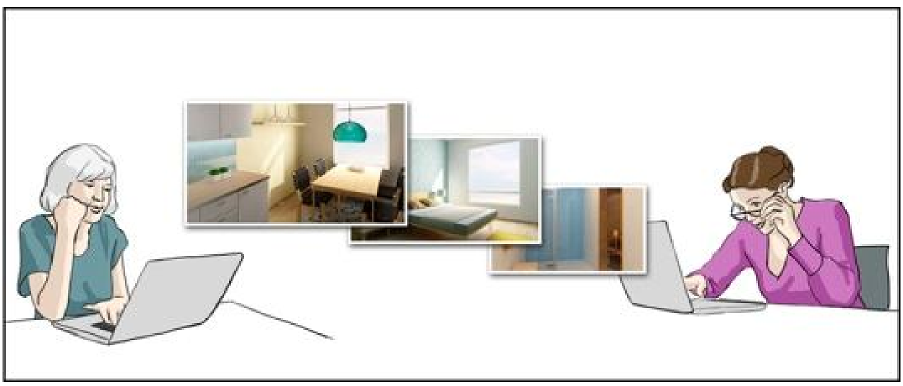


Fig. 4. Couple is moving back from abroad, and they are making interior design for new home.

Scenario 3. Interior Design Contest for Design Bloggers

'3D and AR interior design' service is organizing a contest concerning new homes. Five popular decoration bloggers/interior designers are designing the interior of similar three-bedroom apartments in a new terraced house with the help of the service. The bloggers have a wide range of different home furnishing products available for the virtual design to make any styles they like. Several home furnishing products companies offer downloadable models of their products. Customers can follow the construct of five different plans, comment the solutions and share the links for their friends. The most enthusiastic customers can make their own versions of the decoration plans and share them with their friends.

After a very tight and controversial contest the winner is announced: simple Scandinavian functionality beats romantic vintage country style. The winning designer is rewarded. The winner's interior designs are actually so popular that a couple of apartment buyers end up making their home furnishing according to the visions of the winner.

Then the styles of the contest are saved in '3D and AR interior design' –service. Many users are especially interested in winning home furnishing products and while browsing the furniture, users are able to see other related products in the service.

Fig. 5**.** Interior design contest for design bloggers.

6.2 Presenting Example Applications and Results of the Survey

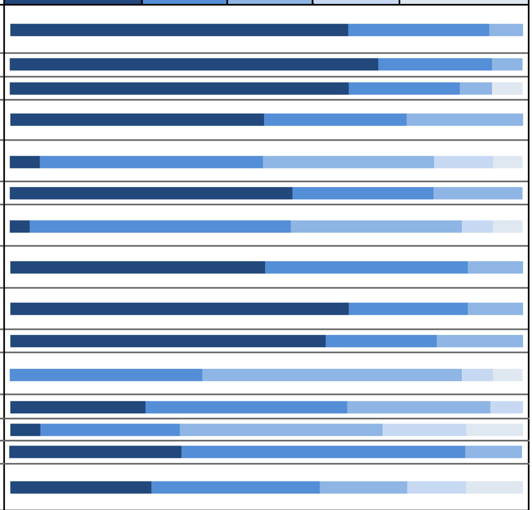
After evaluating scenarios, participants were introduced with three existing example applications that provided interior design services. Most of the participants had at least some experience of using virtual designing or furnishing programs before. They have used or tried several different programs for planning for themselves and for the customers.

The research group had benchmarked these selected applications for the focus group. The participants saw only layout images of existing 3D- and AR applications and they were given a short description of the benefits and similarities to the hypothetical future service concept. Participants were encouraged consider primarily the most essential features of the applications by keeping in mind the future design service concept. Furthermore, participants were encouraged to consider predominantly about the most essential features of the forthcoming application that would be useful for their field of expertise.

After presenting scenarios, focus group participants were familiarized with results of the survey. The participants paid particular attention to a table, which presented the results of most high valued products of the service (see Table 3.). It was seen important that participants had the impotant products selected by the customers available while creating they ecosystem discriptions. The table presented most important products to be: wallpapers, paints, plaques; floor materials; furniture; immovable furniture; storage places and interior textiles.

Table 3. **Table presents most important interior design products determined by 250 respondents of the preliminary online survey.**

	Value: 5 (5 = ext. important)	Value: 4	Value: 3	Value: 2	Value: 1 (1= not important)
Wallpapers, paints, plaques and other surface materials (avg: 4,61)					
Floor materials (avg: 4,67)					
Furniture (avg: 4,44)					
Interor textiles (curtains, carpets etc.) (avg:4,28)					
Interor supplies (e.g. candles, vases) (avg: 3,33)					
Lamps (avg: 4,39)					
Home electronics (e.g. TV, HiFi, computers) (avg:3,44)					
Faucets, sinks, lavatory goods etc. (avg: 4,39)					
White goods, immovable furniture (avg: 4,56)					
Repository, cupboards (avg: 4,44)					
Mirrors, pictures, decorations (avg: 3,22)					
Shelves (avg: 3,89)					
Tableware (avg: 3,00)					
Domestic appliance (avg: 4,22)					
Building material (e.g. floor drains, valves etc.) (avg: 3,56)					
Altogether **100%**	40%	33%	20%	4%	3%



7 Set-Up of the Co-design Session

The co-design phase included two phases and two sketching tasks: the conceptual models of the ecosystems of the service and sketching with more specific objective: the interface proposals of the service. Because the focus group participants were seen as service providers, the emphasis of the co-design session was on the *service ecosystem* of the concept.

At first, participants were encouraged to identify their role in the service system. It was decided mutually in the sessions that each participant would define her role as an ambiguous *designer*. Participants were then divided into pairs, and each pair was encouraged to produce a sketch of the ecosystem in the form of a flowchart. The descriptions were expected to include:

- All necessary stakeholders and elements (products, services, technologies);
- How all stakeholders and elements were connected to the ecosystem, and
- Which were the most important stakeholders and elements (using a tree-level scale).

The participants were encouraged to think about the application through discussed scenarios, and to exploit the information from the online survey and demonstrated applications. In the sketching phase, participants were provided with sketching tools: paper, pens, cardboards etc. Other materials, such as used e.g. in IDEO's tech box [23]: color schemes, pieces of wallpaper, images of furniture etc. were available for inspiration and reference purposes.

Following the sketching phase the focus group participants shared their ideas with others. After presentations, participants improved each other's ideas by paying attention to the application definition statement, scenarios, and, most importantly, personal interest.

8 Results

Participants provided detailed information on the qualities of the service during the introduction, while sketching the ecosystems and, finally, when considering the AR features for the service. The following presents the results of the discussions, the ecosystem sketches, interface descriptions and the participants' AR use cases with detailed considerations.

8.1 Comments Relating to Scenarios

Pre-made scenarios were first presented, discussed and evaluated in the focus group sessions. The preference of interior designers for using very simple design tools in the presented cases was emphasized by the participants, who stressed that usability would be the crucial factor for their interest in using the system. Participants assumed that the real, accurate sizes of the apartment, rooms and furniture were the most critical individual features of the service system. Besides size, the most important qualities for the products, furniture and representative 3D models were stated to be style and color. It was considered reasonable, however, for color to be merely suggestive – e.g. fair, mid-dark or dark – to give an impression of the overall design. Furthermore, participants thought that placing old, existing furniture in the design was even more important than buying new furniture through the service.

It was stated very clearly that a design process often begins by placing existing furniture – an ancestral cupboard or piano, for example – in place, with this piece or artifact defining the overall design plan. However, participants speculated that there might not be any party interested in providing such a service. If the service were to concentrate exclusively on selling new furniture, this would mean all major furniture providers having all their products available in the service system.

Concerning the sharing of design ideas through social media, participants remarked that if they were providing services themselves they would prefer to share their ideas with other interior designers, design enthusiastic people or customers. Designers suspected that general users of the service would also prefer at least semi-professional feedback on their design plans. Sharing design plans with a wider audience, or with friends and family, were seen irrelevant. The participants who were design amateurs were pleased by the idea of the scenario – presenting a home decoration contest (see Fig. 5) – perceiving that the special knowledge and expertise of interior designers and design amateurs could be fully utilized through the contest.

8.2 Comments Relating to Results of the Survey and Example AR Applications

Participants subsequently evaluated some results of the survey they had all responded to. They paid especially attention to a table, which presented the results of most high valued products of the service. The groups agreed on most of the products to be important for an interior design service, but they remarked that the product categories of the service would depend much on the nature of the task. For example a renovator requests different categories than an interior designer. The participants wished this table to be seen later, during the co-sketching of the service ecosystem.

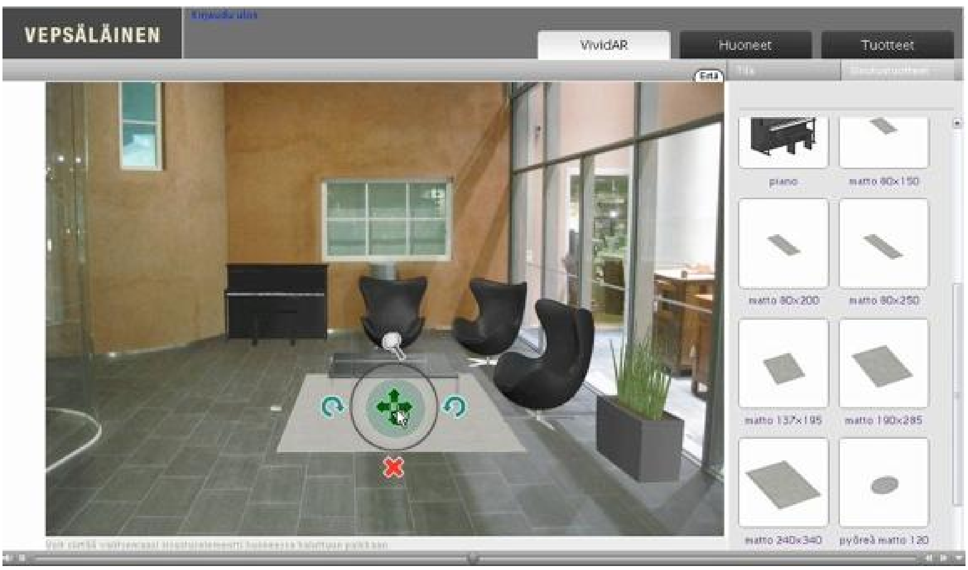


Fig. 6. An interior application that utilized AR technology by VividWorks Ltd[1].

[1] http://www.vividworks.fi/vividplatform

Fig.7. Another example of an interior design application.

Then Participants saw three example applications that were benchmarked by the research group. The applications provided 3D and AR functionalities for creating interior designs. Participants were given an oral description of the benefits that were the criteria for selecting these specific applications.

Participants evaluated presented applications in detail. The most important comments related to the visual appearances: the aesthetics. Participants emphasized that the 3D environments and models needed to be attractive and realistic. The realism brought to interior scenes by the showing of lights and shadows and textures in detail, for example, would make them more convincing. It was also seen as advantageous to induce the user/designer to feel that decorating rooms and creating plans was "leisure activity" – that it was fun to spend time in this way and to explore the service.

As much as the participants valued the idea of interior design contests, the design competitions in these particular example applications seemed to lack the purpose: there were too many of them with no reward. In addition, the most important priority was stated to be the overall costs of the products and services. The existing services, however, only showed prices for single articles.

8.3 Sketches of the Service Ecosystem

After the introduction phase, participants created system concepts in pairs and presented them to each other. The pairs considered the most important factors of the service together with another participant, who was not acquainted. The following examples illustrate the ecosystems and shows how they were used as sketches of thought. Figures 8 and 9 are constructions of the models participants created in Finnish, and they present interpreted information of the models.

Figure 8 presents an example of a concept made by one of the pairs (pair 2: R3 + P1). The pair explained that the ambiguous designer and the service tool were identical (as it is the designer who uses the tool). The first task was to feed the background information and facts into the system, e.g. the floor plans. The sketch contained a two-way arrow – at this point the information either exists or has to be created. The main service providers in the cooperation were interior decorating stores (for wallpapers, floor and wall materials) and furnishing companies. The existing furniture was equally important – "*the past life, which does not vanish when a new home comes along*".

Service providers were the second priority: the individual designers who offer their services, or could be accessed through the service. A third priority was logistics; those who put all the pieces together and provide complete light decoration services, for example. This was followed by accessories, e.g. lighting providers and art suppliers. The sketch also described the chronology of events.

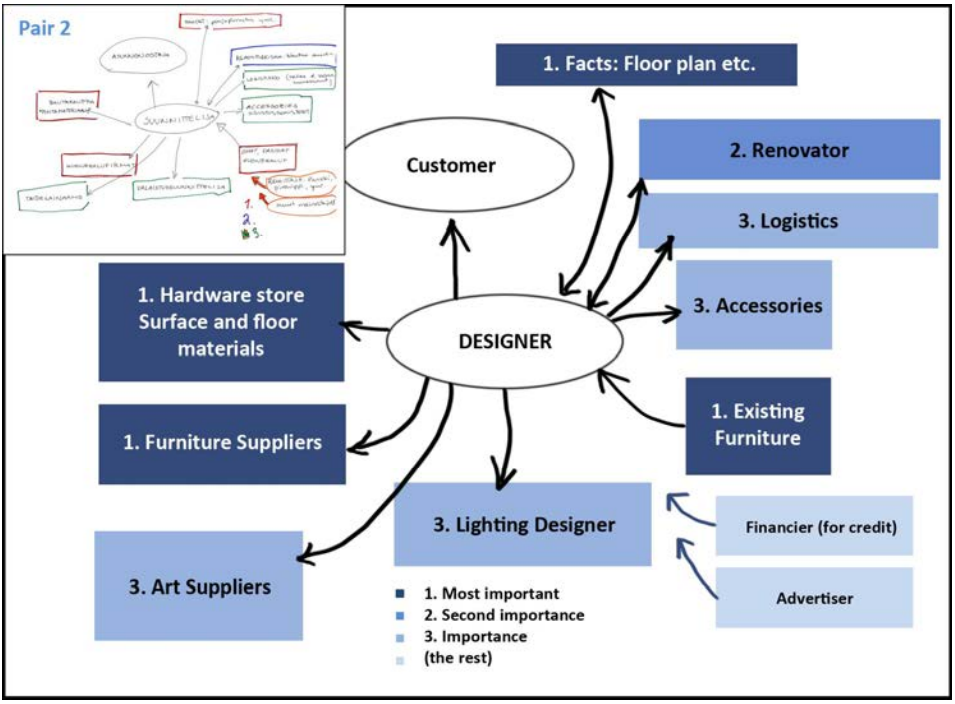


Fig. 8. Service ecosystem made by pair 2: R3 + P1. Participants' sketch is in the upper left corner *(in Finnish)* and reconstruction presents the importance of the factors.

Pair 1 (raters: R1 + R2) explained that in this design-driven service, the customer and designer have two-way relationship, when they are creating interior design plans for multiple purposes (see Fig. 9; bottom, left). They emphasized that the most critical design phase occurs after an apartment has been bought and the service should be designed taking account the matter. Key service providers were the hardware stores, do-it-yourself shops and interior decoration providers. Furthermore, the furniture providers may offer a piece of furniture as well as ready-made collections through the service, and it was seen important that the product providers updated accurate information about their supplies. It was highly important that the overall supply of the products in service was satisfactory. This pair recited that most intriguing attraction for designers, and especially for design amateurs, would be the design competitions, which would be shared by social media.

Pair 3 (raters: R4 + R5) explained that the most important part of the service concept was the customer who determines the target situation, the budget and the most important needs (see Fig. 9; bottom, right). The needs of the service may vary from simple styling to more profound renovation. The first task was the call for bids for suppliers, service providers and HPAC-planning (heating, plumbing, air-conditioning). In an interior design process, the most important part was stated to be the mood and the impression – and thereby the providers of wallpapers and interior textiles deserved a strategic role.

Pair 4 (raters: R6 + R7) explained, that in the service system, at first, the customer determines individual needs and functions of the interior plan (see Fig. 9; top). First operation would include typing in the square meters and the budget - a few criteria that the user (customer) of the service could determine by her/himself. Most important suppliers would be the providers of the surface material, furniture and lightning i.e. hardware stores and decoration shops. The overall supply of products must be wide-ranging and there should be different alternatives for various price scales. Also the special/unique artifact suppliers could easily offer their products through this service. Additionally, timetables of the service providers should be accessible, i.e. private entrepreneurs could notify their availability. There should also be direct contact information for boards of construction. Users of the service in turn could comment about the services by e.g. granting stars for good service. In this case recycling meant that e.g. a customer could save money by taking care of the demolition work.

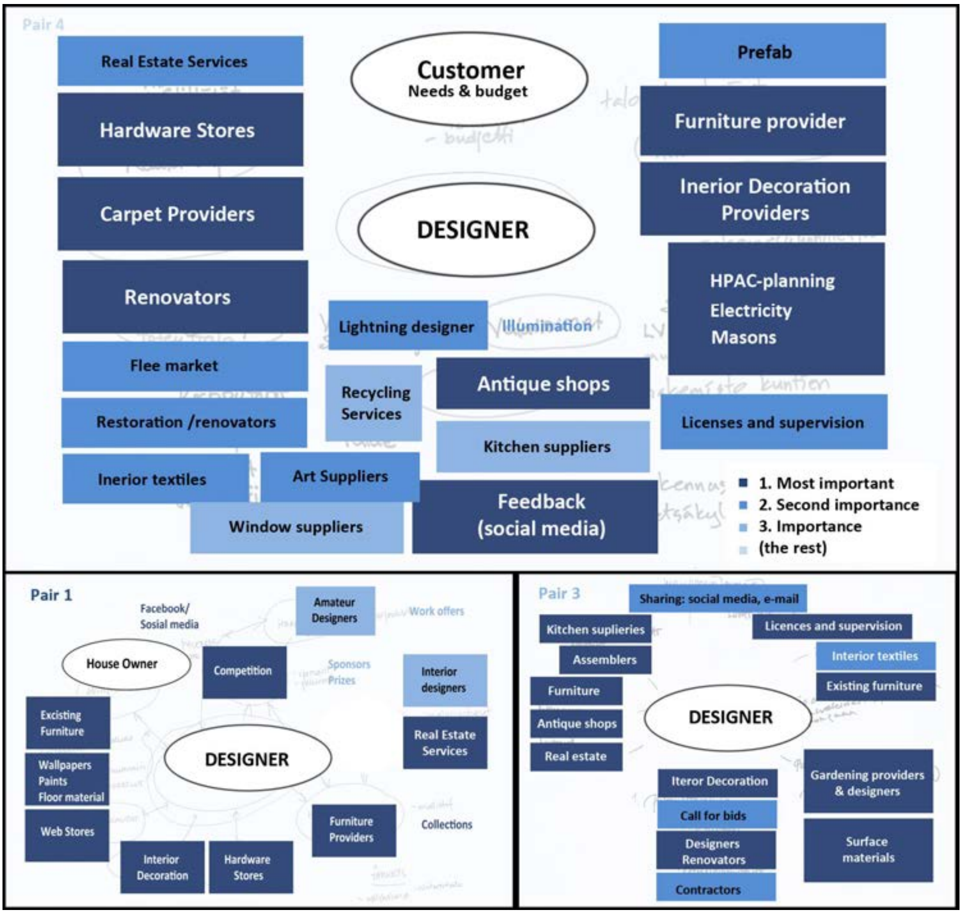


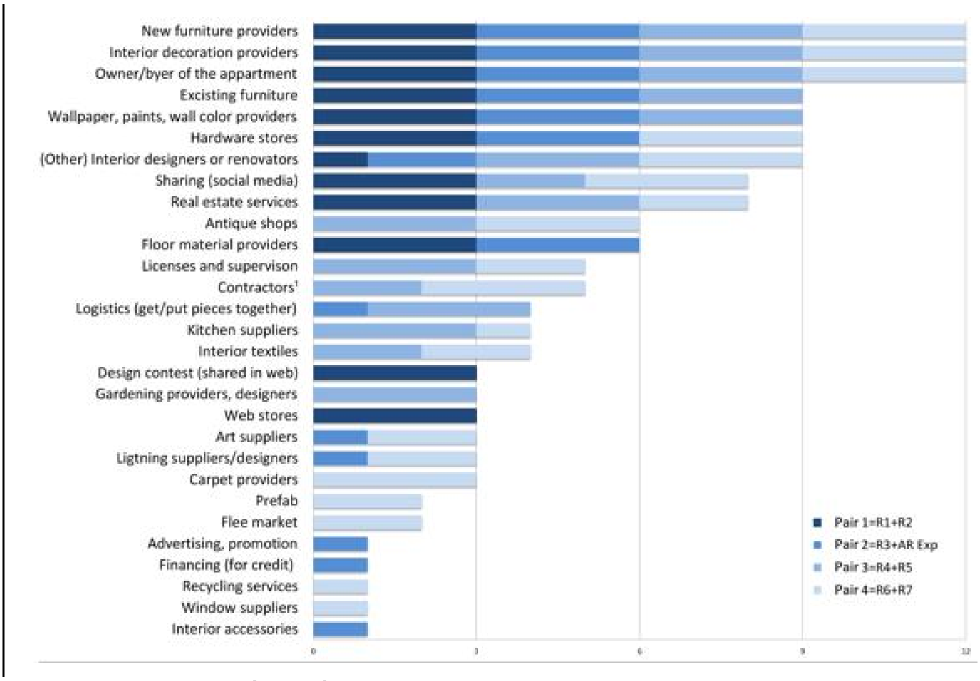
Fig. 2. Reconstructions of the ecosystem sketches made by pairs 1,3 and 4.

Table 4 presents the results of the service ecosystem sketches, and the conclusions of the co-sketching session. Participants were encouraged to determine the importance of the factors using a tree-level scale. For the most important factors, participants used numbering, different color, or stronger line, and confirmed and explained the importance of the services after sketching the content. As the table shows, participants thought that the new furniture and interior decoration providers were key factors in the service. The participants perceived themselves in the co-design situation as designers, but while creating concepts all mentioned the importance of the customer relationship. Also, all mentioned the other designers – competitors or designers with different expertise. The participants highlighted some new providers to be included in the service: kitchen-, window- and carpet providers, antique shops, flea markets, art suppliers, gardening-, lighting- and 3D-model designers of existing furniture. From this viewpoint the service was seen as a cluster for smaller providers.

As novel ideas, participants emphasized that the price of furniture, material and accessories would constitute the essential feature of the concept. It was therefore considered important that the total cost of the new furniture and design alterations should be clearly visible. One group remarked that the customer could apply for a loan from a credit provider if it were possible to refer to an estimate provided by the service.

Because the information was qualitative there was some overlapping with the service providers presented in the table. Some participants, for example, mentioned hardware stores, but described them later as interior decoration providers, and placed both of them in their ecosystem sketches. There were also some conflicts relating to participants' statements of preference during the conversations, and how they were implemented in the ecosystem sketches. For example, all participants emphasized the importance of old, existing furniture in the service, but the it nonetheless failed to receive the full amount of points in the analysis.

Table 4. Results of the service ecosystem sketches. If all pairs *(1–4)* thought a service was most important, the service received 12 points.



[1] Contractors = e.g. HPAC-planning, electricity, masons

8.4 Sketches of the Hypothetical Service Interface

After sketching the service ecosystem, the focus group participants (R4-R7) concentrated on thinking about the service concept further by sketching individually the service interface. Their assignment was to create the entering page of the hypothetical service application, by employing the ecosystem descriptions. After designers had finished drawing their sketches, they explained the content to other participants, one at a time.

Participants' sketches of the service interfaces are explained in this article thoughtfully. They provide individual, very aesthetic, examples of the approaches for developing further the service interface that were created from each interior designers' point of view, and were based on their own experiences. In the following are the verbal descriptions and sketched interface concepts of the participants.

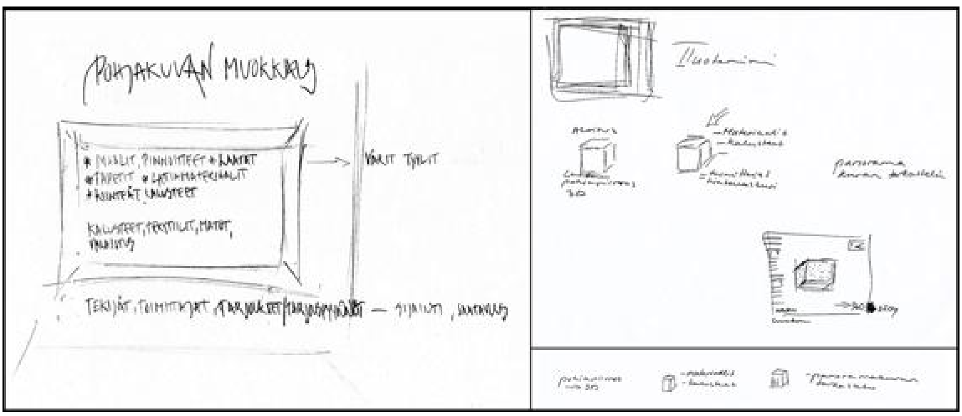


Figure 10. User interface from participant R4 and R7.

The participant R4 explained the interface she created (see Fig. 10; top, left) as follows:
“All the main elements should be available in the service by one glance, plus the name of the service and a stylish picture. The first task is to operate with the 3D plan (at first select or load it). The floor plan is always at the center of the layout. Further actions the user may select from any category: materials, furniture… When the materials and furniture are being added to the plan, there is a price counter at the corner, so that the user knows when the budget has been exceeded. When the plan is finished, user may review it from a panoramic 360-degree view. For it is only that way possible to see if there are any mistakes in the design. And then it should be possible to go back and re-design the plan.”

The participant R7 explained her interface concept (see Fig. 10; bottom, right):
“Selecting the floor plan is the first operation in this service too. It should be very simple to import one’s own plans to the service. The following step is to select the paints, coating, wallpaper and immovable furniture. After that, there are rest of the furniture, textiles, carpets and lightning. After the user has selected paints or coating, there is a selection of colors and styles. All the time, it should be easy to toggle between 2D and 3D plans. In the service, the contact information of the service providers should be clearly attainable, the location and availability of the providers and the possibility to submit invitation for tenders.”

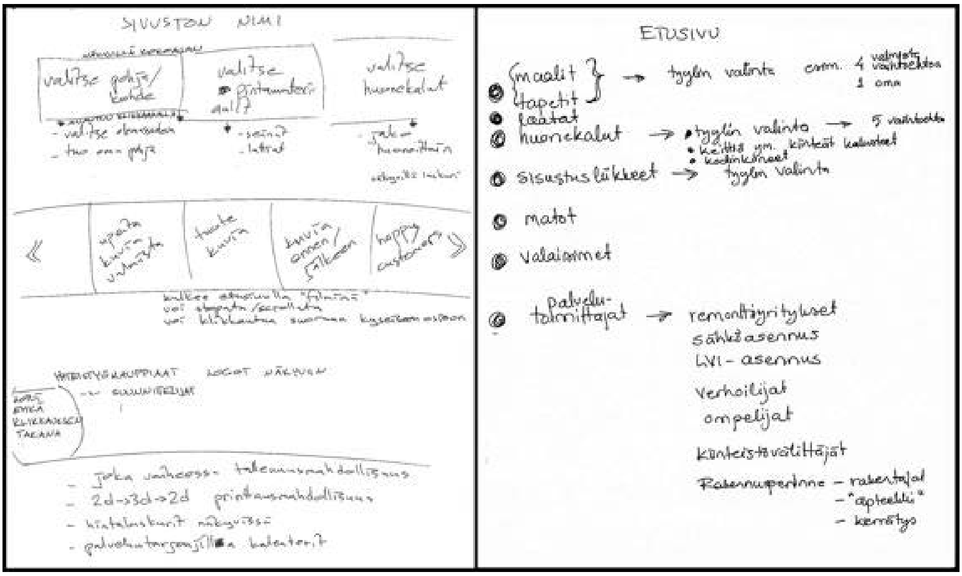


Figure 11. User interface from participants R5 *(left)* and R6 *(right).*

The participant R5 explained her interface concept (see Fig. 10; top, right):
“There must be clear, large buttons for “grandmas” - I like them like that. At first, the user selects the 3D plan, by either bringing it in to the service or selecting a suitable one. When processing the plan, user first chooses the walls, or any other surfaces - there is a simple menu bar from witch to choose the materials. After that comes the furniture. There should be only three steps for working with any kind of design. The plan should be allowed to be saved in any phases, because the work might be interrupted (if a child wakes up, for example). Then there should be two alternatives for publishing: one for the designer (more like a storing place), and another, public place. But there should be restrictions with the latter one also: it could be published to friends, customers or anyone.

In addition, there should be a film roll of pictures – so that the service is more attractive. In the film roll there could be images of furniture, product- and service providers and design plans made by users. It is possible to stop the roll at any time, and look more closely at the interesting pictures, and find all the information relating to it. These kind of mood creating images are very important when communicating with customers.”

The participant R6 explained her interface concept (see Fig. 10; bottom, left):
“There are seven main categories where to start, arranged by the products - except the last one, which lists all service providers. When the user is proceeding with a choice of product, s/he first selects the style. There are e.g. four default styles (country style, modern etc.) and one that the user has created, and the selection guides all the browsing activities. User selects e.g. the furniture; and it is possible to select also the immovable furniture, or the white goods, as they are usually integrated with the immovable furniture.

Interior decoration shops are in their own category, because they usually provide different kind of products. Service providers are e.g. renovation firms, assemblers, upholsterers, sewers and real estate agents. The traditional building trade is one category too."

8.5 Ideas for Augmented Reality in Interior Design System

After sketching the service ecosystem concepts, the focus group participants thought more thoroughly about the AR features of the interior design service. Three topics were highlighted above others in the discussions:

- Realistic lighting,
- Number and variety of furniture models available (including 3D reconstruction of existing furniture), and
- Search functionalities.

Based on their experience, participants emphasized how the lighting conditions affected the overall feeling and atmosphere of a space – and how difficult it was to explain for the customers. By using the AR technology, they saw an opportunity to visualize lighting effects: e.g. an ideal system would show the space in realistic lighting in the evening, morning, winter or summer, or according to the position of the windows. This would show the virtual apartment in a more realistic light: *"All dark corners during winter days, and harsh light during spring"*. Besides the ambient lighting, participants pointed out that it would also be useful to be able to model and visualize the lighting effects of different light sources e.g. to demonstrate the accurate size of selected spotlights.

Designers explained further that they constantly experienced situations in which they had no tools to communicate with the customers e.g. about the colors of the walls. One designer described such a situation: *"The effect of black walls are unimaginable for most customers, as white walls are still so common, but the atmosphere could really be altered by simply changing one wall to black."* This situation could be demonstrated quickly with on-site AR or VR technology.

The participants created use cases that could employ the AR technology, presenting a case in which a person was interested in a particular apartment. With this type of use the person could take pictures of the physical apartment and furnish it later virtually, at home, using the AR service.

The participants raised the issue of the visual quality of the design, which is highly important in interior design planning processes. The participants stressed the importance of the rendering quality of virtual objects: the application should be able to produce realistic materials and lighting effects on virtual objects. Participants stated that they would not engage AR features in the service unless the quality correlated sufficiently with the real environment.

Another important issue was that the availability of virtual models should not restrict the inspiration of a design. If the designer has e.g. an antique furniture model in mind, it should be possible to add it to the interior design plan or at least to represent it using an almost equivalent model. The same need applies to existing furniture; the user should be able to add virtual counterparts of the furniture easily into the design. This means that the 3D-object library should be large, and should contain generic objects whose color, size and materials could easily be changed. Alternatively, designers should easily be able to create their own models e.g. based on images of an item of furniture. The service should also contain smaller objects, such as curtains, plants and flowers, paintings, posters and photo frames. Participants hoped for a sophisticated database search that enables search by color, style and size. Typical situations were described as e.g. *"I need a chair of this size…"* or *"I want a reddish couch…"*

The use cases that the participants ideated brought out both desktop and mobile use of the service. On one hand, they described situations were the service was used on site to visualize something. On the other hand they described use scenarios where the service was used on desktop manner, e.g. the pictures taken on site were later augmented by using the service. There were no preferred devices, or preferences concerning mobile vs. desktop use.

9 Reflection: Technological Feasibility Concerning AR

Concerning the remarks on the AR functionalities, it was said that virtual lights and shadows affect not only the visual quality perceived by the user, but also the realism of the augmentation. In other words, virtual objects seem to hang in the air if they are not attached to the floor with virtual shadows. Virtual lighting, similar to real lighting, embeds the virtual furniture as part of the environment. It is also possible to adjust virtual lights easily, according to real light sources, with user interaction in interior design application [24].

Photorealistic rendering, i.e. the production of photo-like 3D graphics, is computationally demanding, similarly in applications where live video feed is augmented. However, still images are well suited to interior design applications [23], and computation time is therefore not an issue. It is possible to measure the real lighting conditions of the environment, adapt the virtual object to it, and produce adaptive photorealistic AR [25].

Participants did not have any specific discussion concerning the technological devices. However, some requirements came up indirectly; the visual effects and graphics needed to be good quality, and the display needed to be large enough to present the interor design visualizations. The performance, the graphics driver and the display, are easily dealt with in PC environment. However, in the design of a mobile service, the end-device and its capacity, needs to be considered. The service might do more processing on the server side and actually the only requirement for the end-device would be adequate data connection and suitable display, common attributes of modern tablet-PCs, for example.

The participants expressed a need for a large object library that supports creativity, together with sophisticated search functionalities. The challenge of a model library lies in economics: how to create a business model that supports the creation and sharing of 3D models. We may assume that if an interior design service has a sufficient number of users, the creation of a large number of 3D models would be viable.

Altogether, Augmented realty (i.e. features using images of a real apartment), were considered beneficial for interior design and small renovations. For massive renovations and new construction, totally virtual 3D design service might be more beneficial.

10 Framework for Co-designing Complex Systems

Focus group evaluations and co-design sessions provided adequately new information for further design and development of interactive interior design services that utilize 3D and AR technology. The presented research case study provided information for a genuine purpose, to tasks that were initially set by the research program and partaking companies. The process proved to be successful, if it is measured by the quantity of ideas and quality of the new ideas. Since the participants' interior design expertise was extremely high, they were able to create several new, aesthetic ideas for the interior design system concepts. Encouraged by the results of the study, we propose the following framework for utilizing several innovation methods when co-designing multifaceted concepts with users for e.g. system-, interaction- and service design purposes:

Pre-co-design phase

- Defining the concept - with all the relevant stakeholders involved
- Collation of information about a specific context (e.g. by benchmarking applications)
- Specifying the information meaningfully and as a result, constructing stories or scenarios
- Defining the end-users and critical users
- Gathering quantitative information e.g. by organizing a preliminary online survey for both/all groups
- Redefining the concept

Co-design phase with critical users

- Presenting the information, in this case:
  - The concept definition
  - Pre-made scenarios
  - Benchmarked applications
  - Results of a survey, presenting wider sampling
- Co-sketching the conceptual models of the system/service
- Collating and sharing the new information and interpreting results
- Sketching with more specific objective (a specific product/system/service)

Post-co-design phase

- Defining the criteria and providing interpretation of the co-design material
- Redefinition of the concept, including all stakeholders

Co-designing the concept in the initial phase of the design process, with the contribution of all participants, assist in creating an experience-based structure for a forthcoming future service or system. We believe that this design-led (design-related) study provided somewhat optimal conditions for trying out the proposed framework, but the framework itself is suitable for multiple purposes, especially for multifaceted design processes.

11 Discussion

This article illustrates a user-driven innovation process for designing new concepts, interfaces and outlines for augmented reality in the field of interior design. The outcomes of he process are described in detail, because the information gained by conducting the two focus group evaluations may benefit many audiences: several stakeholders operating in the interior design field, software manufacturers of various fields and any parties interested in employing augmented reality features in many environments.

Table 4, the results of the service ecosystem sketches, presents the conclusions of the co-sketching phase in which all the participants took part of. The sketched ecosystems held all the important elements of the novel interior design service, and as the table shows, participants thought that the new furniture and interior decoration providers were the key factors of the service. It was significant, that all participants emphasized the importance of old, existing furniture in the service. However, some participants speculated that there might not be any party interested in providing such a service. This article tries to raise issues of this kind in front and present the unobvious demands of the interior design field.

The participants perceived themselves in the co-design situation as ambiguous designers, but they all mentioned the importance of the customer relationship. The service was created in this study from the viewpoint of the designers, but it was considered that different kind of design, constructing and renovating designs require different kind of approaches. In that sense, it is highly important who are considered to be the users of the service – the fact influences how the service and the interface should be designed. Also, all of the participants mentioned the other designers, competitors or designers with different expertise, and call for bids to have influence in a usable service. The participants highlighted some new providers to be concluded in the service: e.g. kitchen-, window- and carpet providers, antique shops, flee markets, art suppliers, gardening-, lightning- and 3D-model designers of existing furniture. In this viewpoint, the service could act as a cluster for smaller providers.

12 Conclusion

After studying the most important requirements of the critical users for the AR technology, it can be said that most ideas could easily be implemented in an interior design service system. When it comes to participants' needs for modeling existing furniture, however, it may take some time before practical solutions are available; current solutions for 3D reconstruction (i.e. construction of a three-dimensional model of an object from several two-dimensional views) require too much involvement and knowledge from the user. Research is nevertheless moving towards rapid 3D reconstruction on mobile devices [26]. In future interior design services, the user is expected to scan the interior environment effortlessly with a mobile device, and even obtain modeling of an existing item of furniture.

As novel ideas, participants emphasized that the price of furniture, material and accessories were one of the most essential features of the concept. Therefore, it was seen to be important that it was clearly visible how much all the new furniture and design alterations would cost all together. Also one group remarked, that in addition, the customer could apply for loan from a credit provider by making reference to the estimation of the service. Focus group participants, whom we anticipated to be the critical users of the service, in turn described the users of the service as: interior designers, interior architects, various decorators, model creators, lighting consultants, electrical consultants, small or large furniture companies (or individuals), decoration- and renovation providers.

The sketching approach for empowering a co-design process proved to be a flexible and productive method of involving users in the innovation conception phase, and for perceiving a user model of an interactive design system. The results of the service ecosystem sketches presents certain evidence that it is also conceivable to analyze users' models. Moreover, because of the ecosystem descriptions, the highlighted issues were discussed more thoroughly in the focus groups. In exploiting sketching as a means of involving users in the interaction design processes, the key finding was that during the co-design session the sketches remained in the custody of the participants: even if the conversation and new information led opinions and ideas along different courses, participants expressed their judgment's by referring to their sketches. For pursuing user-driven innovation concepts through sketching, according to this study it is justifiable to say that critical users together with facilitators and developers can contribute to the development process by a sketching method, if they have sufficient and properly formed information. Moreover, the sketching method has enrichment value when pursuing the human-driven part in design processes. Justification for using the framework of co-designing complex concepts we presented in this article is, that:

- User role broadens from research subject that comments ideas to an active co-designer
- Users design ideas provide complementary material in the initial design phase for developers
- The general acceptance of the idea can be evaluated and alternative designs can be compared to each other
- Design decisions become more explicit and easier to comment on
- Users' goals and needs can be defined in terms of current and envisioned new practices

Already in former studies, sketching approach was learned to be an efficient, flexible way to quickly generate, develop and communicate design ideas. In our study, user's sketches were used as tools that may be used for further conception. The further use will illustrate whither sketching, as a method, will provide usable approach to perceive the users' conceptual model of more complex design processes, such a service design process.

Focus group user evaluations and co-design sessions provided adequately new information for further design and development of interactive interior design services that utilize AR technology. Since the focus group participants' interior design expertise was high, they were able to create several new, aesthetic ideas for the interior design system concepts. AR technology was mostly speculated upon by offering examples of existing AR features, yet the participants were able to provide valuable feedback: AR use cases, and the fact that the evaluations of the feasibilities were based on the experience of interior designers.

Acknowledgments. The research study was carried out within the Adfeed -project, which was supported by TEKES as part of the next Media program of TIVIT (Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT). We gratefully acknowledge the preliminary work relating to scenarios, benchmarking the applications and carrying out the initial survey for real-estate customers: the researchers at VTT Technical Research Centre: Virpi Oksman, Minna Kulju, Antti Väätänen and at University of Tampere: Mari Ainasoja, Jorma Riihikoski and Juhani Linna. And finally, Minni Kanerva, who provided the illustrations for Figures 2–5.

References

1. Schuler, D. and Namioka, A. Participatory Design: Principles and Practices, Lawrence Erlbaum Associates, Inc., Hillsdale, New Jersey (1993)
2. Kaasinen, E., Ainasoja, M., Vulli, E., Paavola, H., Hautala, R., Lehtonen, P., and Reunanen, E., 2010, *User involvement in service innovations*, VTT Research Notes 2552, Espoo, Finland
3. Krueger R.A and Casey M.A (2000) Focus Groups: A Practical Guide for Applied Research, 3rd ed. Thousand Oaks, CA: Sage Publications.
4. Carroll, J.M. Making Use: Scenario-Based Design of Human-Computer Interactions. MIT Press, MA, USA (2009)
5. Greenbaum, J. and Kyng, M. (eds) Design at Work: Cooperative Design of Computer Systems. Lawrence Erlbaum Associates, New Jersey, USA (1991)
6. Cassim, J. and Dong, H. 'Critical users in design innovation'. In Clarkson, P.J., Coleman, R., Keates, S., and Lebbon, C. (eds.) Inclusive Design: Design for the Whole Population, Springer-Verlag, London. pp. 532-553 (2003)
7. Buxton, W. Sketching User Experiences: Getting the Design Right and the Right Design. Morgan Kaufmann, San Francisco, USA (2007)
8. Badke-Schaub P., Neumann A., Lauche K. and Mohammed S. (2007): Mental models in design teams: a valid approach to performance in design collaboration? CoDesign: International Journal of CoCreation in Design and the Arts, 3:1, 5-20
9. Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. and MacIntyre, B. Recent Advances in Augmented Reality. IEEE Computer Graphics and Applications, Vol. 21, No. 6, pp. 34-47 (2001)
10. Mann, S. Mediated Reality with implementations for everyday life. Presence Connect, MIT Press journal PRESENCE: Teleoperators and Virtual EnvironmentsPresence (2002)
11. Milgram, P., Takemura, H., Utsumi, A. and Kishino, F. Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum. In Proceedings of the SPIE Conference on Telemanipulator and Telepresence Technologies, pp. 282-292 (1994)
12. Siltanen S. Theory and applications of marker-based augmented reality. VTT Science 3. Espoo. Finland, in Press (2012)
13. Suwa, M., Gero, J. S., & Purcell, T. A. (1998). The Roles of Sketches in Early Conceptual Design Processes. In proceedings of the Twentieth Annual Meeting of Cognitive Science Society. Madison, WI

14. Gedenryd, Henrik (1998) How Designers Work: Making Sense of Authentic Cognitive Activity, Lund University, Sweden.
15. Tohidi, M., Buxton, W., Baecker, R. & Sellen, A. (2006). User Sketches: A Quick, Inexpensive, and Effective way to Elicit More reflective User Feedback. Proceedings of NordiCHI 2006, 105-114.
16. Dorst, K. and Cross, N., (2001), Creativity in the design process: co-evolution of problem-solution, *Design Studies*, Vol. 22, No.5, pp. 425-437
17. Pólya, George (1957), How to Solve It. Garden City, NY: Doubleday.
18. Keinonen, Turkka et al. Tuotekonseptointi. Teknologiateollisuus, Helsinki, 2004.
19. Shneiderman, Ben (2002). Human Need's and the new computing technology: Leonardo's Laptop. The MIT Press. Cambridge.
20. Sanders E. and Stappers P. (2008): Co-creation and the new landscapes of design, CoDesign: International Journal of CoCreation in Design and the Arts, 4:1, 5-18
21. Mattelmäki, T.; Design Probes. Doctoral dissertation, University of Art and Design Helsinki, 2007
22. Lucero A., Vaajakallio K. and Dalsgaard P. The dialogue- labs method: process, space and materials as structuring elements to spark dialogue in co-design events, Codesign, Volume 8, Issue 1, 2012 pp. 1-23
23. Kelley, T., and Littman, J. The Art of Innovation: Lessons in Creativity from Ideo, America's Leading Design Firm. Doubleday, New York (2001)
24. Siltanen, S. and Woodward, C. Augmented Interiors with Digital Camera Images. Piekarski, W. (ed.) In proc. Seventh Australasian User Interface Conference (AUIC2006); CRPIT. ACS. Vol. 50: 33 (2006)
25. Aittala, M. Inverse lighting and photorealistic rendering for augmented reality. The Visual Computer, Vol. 26, No. 6, pp. 669-678 (2010)
26. Hartl, A., Gruber, L., Arth, C., Hauswiesner, S. and Schmalstieg, D. Rapid reconstruction of small objects on mobile phones. Computer Vision and Pattern Recognition Workshops, IEEE Computer Society Conference, Colorado Springs CO, USA, pp. 20-27 (2011)

PAPER III

User-centered design of augmented reality interior design service

International Journal of Arts & Sciences, Vol. 6, No. 1, pp. 547–563.

International Journal of Arts & Sciences,
CD-ROM. ISSN: 1944-6934 :: 6(1):547–563 (2013)

USER-CENTERED DESIGN OF AUGMENTED REALITY INTERIOR DESIGN SERVICE

Sanni Siltanen and Virpi Oksman

VTT, Finland

Mari Ainasoja

University of Tampere, Finland

This paper presents key findings on user expectations of an augmented reality interior design service, a service which combines features of social media, augmented reality (AR) and 3D modeling to ambient home design. Our study uniquely bridges all actors of the value chain to the user-centered design of an augmented reality interior design service: consumers, interior design enthusiastics and professional interior designers, but also furniture retailer and digital service providers. We examine the benefits and challenges of applying user-centered methods with three different target user groups; consumers, pro-users and professionals. This paper also describes desired features of an AR interior design service for different target groups, and discusses their technical and practical feasibility. User expectations for AR interior design services were studied with a scenario-based survey, co-design sessions and focused interviews. Altogether 242 consumers and pro-users responded the ambient home design service on the survey. Thereafter, special co-creation sessions with five consumers and two professional interior designers were conducted to develop the concept further with the target groups. In addition, we interviewed four different commercial actors on the field to deepen insights on product expectations. The combination of different user-centered methods proved valuable in the early phases of concept design. It appears that there is a demand for easy-to-use design tools both for consumers and professional users. However, our research confirms that consumers and professionals have different needs and expectations for home design system, and therefore target users should be included in the design process with appropriate methods. Commercial actors see viable business model as most substantial attribute for the service, which must be taken into account in service design as well.

Keywords: User-centered design, Interior design, Augmented reality, Service co-creation, Co-design, Participatory design, Focus interviews, Consumer applications, Scenario-based survey, User groups.

Introduction

At the moment, consumers and professional users have a wide range of different virtual home design tools available on the Internet. Home design services help users to figure out what kinds of building products and decoration materials to pick for a home in addition to furniture, household appliances and home electronics to choose for an aesthetically pleasing home environment. Usually, the services allow model rooms to be created using ready-made 2D floor plans or 3D models.

In the home design concept, VR and 3D graphic systems (such as IKEA Home Planner) typically have functionalities where the user is able to define a 3D space (dimensions of the floor plan, locations of windows, doors, etc.) and insert, move and remove virtual furniture. In AR home design systems, augmented digital images of the real environment are contemplated with virtual furniture (see Fig. 1). Typically, the user can insert, move and remove virtual furniture interactively in 3D over an image taken with a digital camera. In our AR concept, we studied the enhanced possibilities to manipulate the augmented image of environment, for example by removing existing furniture to see better how the new furniture fits in.

In this research project, we considered Web-based interior design concepts with the help of concept sketches and scenarios of fictitious future service. The fictitious, sketched service enables ordinary people to plan easily the furnishing and decoration of their properties using novel technologies, such as augmented reality.

The developed do-it-yourself technology concepts allow users to model their existing home and furniture as well as to create virtual decoration for properties for sale in an online marketplace for home and real estate offering the service. In addition to consumers planning new decorations, the service with its developed AR technologies could be exploited by pro-users, such as interior design professionals and real estate agents.

In this research, we concentrated on the interior design concept, where the AR is part of a service, and on the functionalities of such service. We studied general acceptance with a survey. In addition, we arranged co-creation and interview sessions with several actors representing different roles in interior design and furniture retail to gather different aspects, needs, bottlenecks and targets for future development of augmented reality interior design. Augmented reality can be implemented using several end devices and platforms. In co-creation sessions, we considered a Web-based system that the user operates on most prominent devices — PC, laptop or tablet PC.

This paper is organizes as follows, first we discuss the research methods and theoretical background of user participation in co-creative services, and we describe how augmented reality is used in interior design in general. Then we explain how research methods were implemented and their results; we start with scenario based survey and its results, and continue with co-creation sessions and focused interviews and their results. We end the paper with a discussion of importance of the findings and conclude the results.

Research Methods

We studied three different user groups: consumers, pro-users and professional users. The professional users were professional interior designers and the pro-users consisted of active interior-design bloggers and students of interior design or closely related subject (Figure 1). In addition to users, we included business actors of AR interior design service to our study.

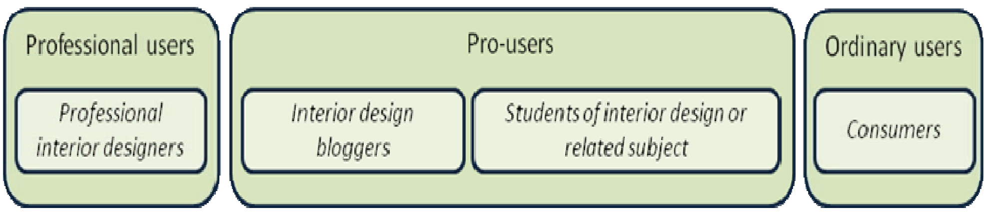


Figure 1. User groups involved in our research: professional users, pro-users and ordinary users. Professional users were professional interior designers, pro-users consisted of interior design bloggers and students of interior design or related subject. Ordinary users are consumers, and referred as consumers in this paper.

We combined different research methods to examine the user-centered aspects and business prospects of an ambient home design concept:

1. **A scenario-based survey** for consumers and pro-users for early concept development of ambient home design service
2. **Co-creation sessions** with consumers and professional users to deepen insights on augmented reality interior design
3. **Focused interviews** of actors in AR interior design service to understand business factors.

Each research method has own specific goals and concentrated on finding out mindset of different user groups (Figure 1). To get a throughout picture of user perspective, we decided to use scenario-based on-line survey to study both pro-users users' and consumers' attitudes and ideas, co-creation session for professionals and consumers, and focused interviews for professional users and business actors (Table 1). These are all methods that support early concept design and user understanding (Maguire 2001).

Table 1. The studied user groups and the research methods applied to each group.

	Scenario based survey	Co-creation sessions	Focused interviews
Pro-users (interior design bloggers and students)	X		
Consumers	X	X	
Professional users (professional interior designers)		X	X
Busines actors			X

The first research method — scenario based survey— focus on user perception with the two target groups chosen for the study, namely consumers who are seeking a new home through an online marketplace and pro-users who have professional or other special interest in the decoration or renovation of apartments. The main focus is on attitudes towards technology and general ambient home design concept. It involves large volume of participants in order to find out "the voice of the masses". We got a total of 242 responses to our survey. The questionnaire also surveyed the attitudes towards social media and sharing of designs.

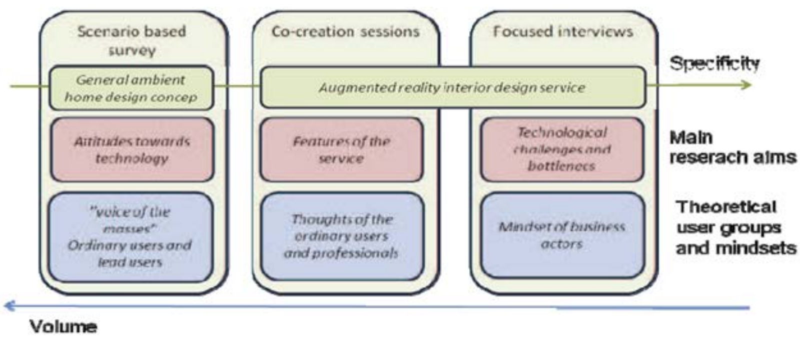


Figure 2. Combination of research methods: The specificity increased to the right, whereas the volume (number of participants) increases to the left. Each method has own specific goals and concentrated on finding out mindset of different user groups.

The co-creation sessions focus on a narrower concept: web based augmented reality interior design service that the user can operate on laptop, PC, or tablet PC. We organized six co-creation sessions; five consumers participated individual sessions and two professional interior designers participated a joint session. The co-creation sessions focused on ideating augmented reality features with discussions and brainstorming. In addition, we explored an existing service to foster discussions, and to concretize augmented reality for the participants.

The interviews aimed for understanding business factors of the service and mindset of the business actors. We interviewed four actors in the AR interior design value chain; a professional interior designer and persons representing a furniture retailer, a company providing interior design on the Internet and a company providing an AR interior design Web platform. The interior designer was female, and others were male.

Consumer can use the interior design service by herself/himself, or she/he may ask professional interior designer, or an interior design company to make the design. The consumer may also turn to an interior design enthusiastic (e.g. interior design blogger) and ask for recommendations. The AR interior design service can be provided through furniture retailer, who gets it from the platform provider, or an interior design company may have their own service. All these actors of AR interior design service value chain were involved in our study (Figure 3).

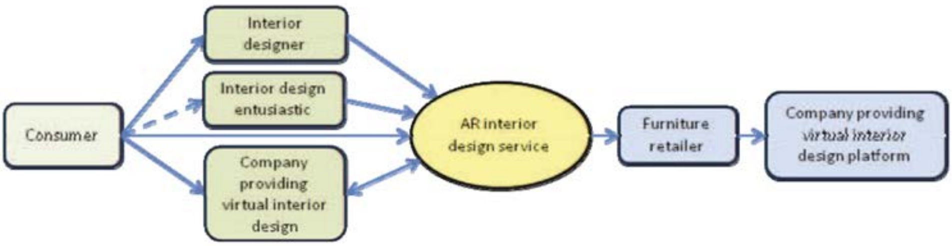


Figure 3. Actors of the virtual interior design service value chain involved in our study. Interior design enthusiastics (that is bloggers in our case) were involved in the survey, consumers in the survey and in the co-creation sessions, and others were interviewed.

In addition to the research described in this paper, focus group co-creation sessions were carried out later with pro-users who answered the survey. These focus groups sketched the user interface and the overall service. Results of these focus group co-creation sessions are described in (Kymäläinen and Siltanen 2012).

Defining User Participation in Co-Creative Services

This paper bridges different user groups and actors in user-centered design of future augmented reality interior design service. User involvement has been pointed out to be especially useful in the early stages of the development process due to the high uncertainty and low formalization of these stages (Alam 2006). Carbonell, et al. (2009) state that user involvement (in their study customer involvement) in development has no direct effect on sales volume; rather, it affects new service success through better quality and innovation speed.

In many research fields such as human-centered design, marketing and media studies, the emphasis on user involvement has shifted from treating users only as passive research objects to taking them into the design process as active co-creators and partners (Kaasinen, et al. 2010). This view has been given different name with a slightly different emphasis in definitions: for example, Weber (2011) lists over 10 related concepts but states that the lack of explicit definitions often leads to ambiguity. Two widely adopted perspectives have been *participatory design* and the *user-centered approach.* Participatory design has often been defined as a shift in attitude from designing for users to one of designing with users.

Co-design to often refers to creative designers and people not trained in design working together in the design development process (Stappers and Sanders 2008), whereas co-creation is also used to refer to collective creativity in general, not limited to product and service design. However, *co-creation* and *co-design* are often used as synonyms, and in this paper we use the term *co-creation* in order not to have confusingly to design terms co-*design* and interior *design*.

It is quite difficult to draw the line between a user-centered design processes to one of participatory experiences. According to Sanders (2002), participatory design is not only simply a method or set of methodologies, but more like a mindset and an attitude about people. It is the belief that all people have something to offer to the design process and that they can be both articulate and creative when given the appropriate tools with which to express themselves.

According to service research, the typical characteristics of services can pose additional challenges for methods of user studies and user participation in co-creation. Traditionally, the characteristics that separate services from goods are considered to include, for example, intangibility and inseparability (see, for example, Lovelock & Gummesson 2004 or Grönroos 2000). Intangibility makes services more challenging to illustrate and evaluate when co-creating services with users (Ainasoja, et al. 2011). The high technical nature of augmented reality features in this case is hardly making this challenge less important. Inseparability emphasizes the active role of the customer in producing the service experience: value is co-created (Vargo & Lusch 2004). For example, Menor, et al. (2002) and Alam & Perry (2002) have stated that service innovation requires a higher degree and new means of user participation compared to a traditional product-centered approach.

The most well-known user type in co-creation is probably the one of lead users introduced by von Hippel (1986, 2005). Lead users can be defined as members of a user population who anticipate obtaining relatively high benefits from a solution to their needs, and are at the leading edge of important trends in a marketplace under study and so are currently experiencing needs that will later be experienced by many users in that marketplace (Franke, et al. 2006; von Hippel 2005). In our case, *pro-users* can be considered as *lead-users*.

Although research about user participation in service co-creation started from lead users, recent studies have suggested that other user groups can also contribute to the early phases of service innovation. Weber (2011), for example, proposes that the main criteria for choosing participating users is that they have some experience of being a user of a service class, and technical expertise is not considered as important. Ordinary users, advanced users, critical users and even non-users can give valuable contributions (Kristensson, et al. 2004; Ainasoja, et al. 2011; Heiskanen, et al. 2007).

"Ordinary users" represent the average person with regard to the use and expertise of the service in question, and they are likely to have only a little knowledge of the technology concerning the service (Magnusson 2009). In our cstudy, *ordinary users* are *consumers* who have a need for interior design, but have no or little experience of using the technology.

Some studies have pointed out that these ordinary users can generate even more original or better ideas than lead users (Kristensson, et al. 2004). Ordinary users produce more original ideas with better user value when they are not trained in the underlying technology. However, these ideas describe the need and cannot usually be implemented as such. With technical consultation the originality of ordinary users' ideas deteriorates but ideas become more producible; users become "copy-cat professionals". (Magnusson, et al. 2003; Magnusson 2009). Instead, ideas improving emotional elements of service experience (such as enjoyment and fun) can be difficult to generate spontaneously by ordinary users (Sandström, et al. 2009).

When trying to understand the needs of users, there is a wide range of different user-centered design methods (i.e. cultural probes, workshops, contextual inquiries, interviews, co-creation sessions, prototyping, etc.), described in detail by Lucero (2009) that could be used. Designing the most suitable way to participate for each participant group is central, because the participation experience itself - enjoying, learning, inspiration - is one of the motivational factors for participants (Füller 2006; Füller, et al. 2007; Hyvönen, et al. 2007). Thus different user groups can make different contributions to the service design and their motivations, skills and preferred ways of participating can vary.

For example, Alam (2006) suggests that including both lead users and ordinary users in the development process is useful. In our study this meant involving both pro-users (lead users) and consumers (ordinary users). Although most of the consumers had no experience of using a co-created service, they could be the most potential users in the future due to their interest in home decoration and renovation. The role of professional interior designers is some between the two groups, they are among the first to use the service, but likely because of processional requirements rather than personal interest.

Augmented Reality and 3D Models in Interior Design

Augmented reality is a profound visualization method for situations where there is a need to show something in a real environment and to enhance user's perception (Siltanen 2012, pages 165-166). It is defined as a real time interactive system that combines real and virtual elements in 3D (Azuma et al. 2001).

Augmented reality can be used in interior design (Siltanen and Woodward 2006; Lee et al 2008), renovation planning (Pinto Seppä et. al 2007; Saito et. al 2007) and in many ways to visualize building and construction projects (Woodward et. al 2007; Golparvar et. al 2009), for example. Augmented reality interior design applications often use still images. However, the user can interact with the 3D augmentations in real time. Thus such systems satisfy the definition of AR (Siltanen 2012, page 23).

Virtual reality (VR) means an immersive computer simulated system. The simplest form of virtual reality is a 3D image that user can manipulate interactively on the computer display. This kind of system is often referred as interactive 3D graphics. Sophisticated VR systems involve special devices such as wearable computers, VR rooms, haptic devices etc. In this work, we consider simple VR/3D graphic systems with no special devices.

Mediated reality refers to a system were something is altered, diminished reality to a system were something existing is removed. Augmented virtuality (AV) embeds real elements to a virtual environment. Mixed reality refers to systems varying from reality to virtuality and their all combinations of real and virtual (incl. AR and AV) (Milgram et al. 1994).

Figure 4. Illustration of AR home design concept.

Ordinary people are not familiar with these definitions and terms are often used indefinitely. In our study, we used term *augmented reality* to refer to *a system that combines real and virtual elements* including all above mentioned technologies when they came up in discussions.

Augmented reality applications may be implemented using different display technologies and devices. A consumer application such as the AR interior design service studied in this paper needs to rely on commonly available consumer devices. That means that special devices such as head-mounted-displays are out of question. Mobile phones, although used in many AR applications (Azuma et. al 2011), have relatively small display and therefore users prefer e.g. laptop PC in visualization applications (Olsson et. al 2012).Therefore, in co-creation sessions, we defined our fictitious service to utilize PC, laptop PC or tablet PC – the most potential devices for consumer level visualization application. Figure 4 shows an illustration of augmented reality interior design prototype using a tablet PC.

Implementation of the Scenario Based Survey

We conducted a scenario-based survey for early concept development. The scenarios described fictional use cases of the sketched home design service. 242 respondents (consumers and pro-users) answered to the service. The scenario-based methods proved valuable in the early phases of concept design. Two pro-users were male, all others were female.

The consumer survey was done in cooperation with an online marketplace for home and real estate. The questionnaire was presented on the web portal, and 205 consumers answered the survey. Most of the consumers did not have any previous experience of using virtual interior design programs.

The pro-user survey was sent to interior design bloggers, and students studying interior design or closely related subject. 21 bloggers and 16 students answered the survey, one of the students studied something else than closely related to interior design. Due to nature of the subject, almost all respondents were female, only two of the students were male.

Scenarios

Four visualized scenarios were used in the survey to help the users to understand the different possibilities of AR, VR and 3D modeling, and to inspire ideating new concepts. Scenarios are fictitious stories which present users with different lifestyles, needs and interests. The scenarios can help to understand the possibilities of AR and 3D technologies, different use contexts and motivations to use the services. The scenarios were 1-2 pages long illustrated stories.

In the first scenario, a young couple is looking for a home and they use 3D interior design service to compare possible apartments. They also share designs through social media and let their friends comment and edit the designs before making their purhasing decision.

In the second scenario a expatriat couple is moving back to Finland and make interior design for their new construction home using web-based service. They discuss the ideas with their relatives in Finland and send image via email. The constructor cooperates with a furniture retailer, and thus they are able to purchase the planned furniture with discount – including installation to the appartment.

In the third scenario, a family makes interior design for their new house with 3D television. They consider different wallpapers for children's room as well as new furniture and home theatre with aestically pleasant loudspeaker system, for example.

The fourth scenario describes a virtual interior design contest open for interior design bloggers among others. The designs are shared through social media and people are able to comment them and vote for their favourite. Figure 5 shows one of the illustrations used in the fourth scenario.

Figure 5. A fictitious scenario: Interior design contest for new construction (scenario 4).

Results of the Scenario Based Survey

The survey concentrated on user attitudes and social media features of the service. 52% of the bloggers and 56% of the students had used virtual interior design service earlier, whereas, only 27% of the consumers had used such service earlier. In addition, 29% of the bloggers and 31% of the student were aware of such services.

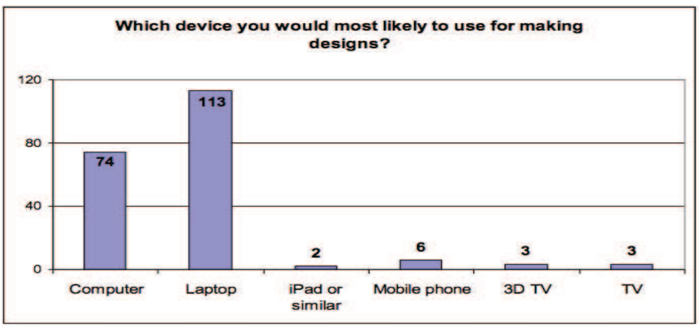


Figure 6. Consumer view to the question “Which device would you most likely to use for making designs?”.

Consumers considered PCs and laptops as most prominent devices for this kind of service (Figure 6). At the time of the survey tablets were still relative rare. The number of tablets has increased since the survey, and people might answer differently now.

48% of bloggers and 63% of the students believe that they will definitely use this kind of service in the future, and 43% of the bloggers and 31% of the students believe that they might use this kind of service in the future. The rest did not have an opinion on the matter.

Pro-users and consumers have different attitudes towards sharing the designs. As we might expect, the possibility to share designs through a blogs is important for pro-users, where as consumers are not so willing to share designs in a blog. In general, consumers appreciate private sharing channels more that pro-users, and pro-users appreciate public visibility more than consumers (Figure 7). Pro-users would use this kind of service for several purposes (Figure 8).

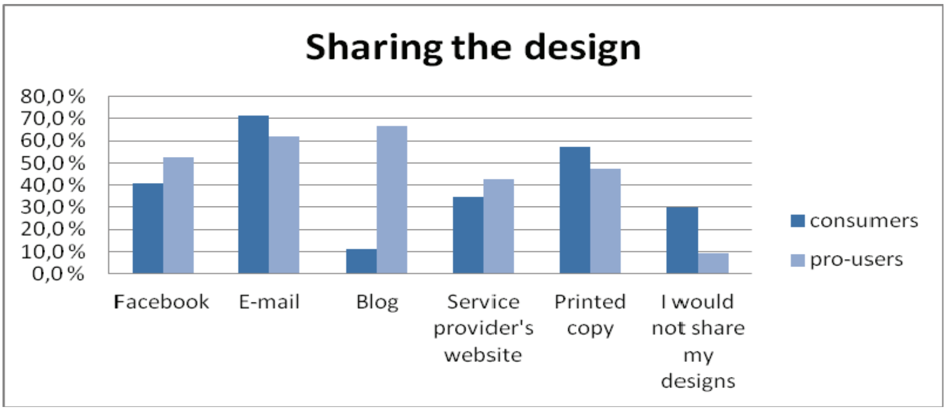


Figure 7. How people would like to share their designs.

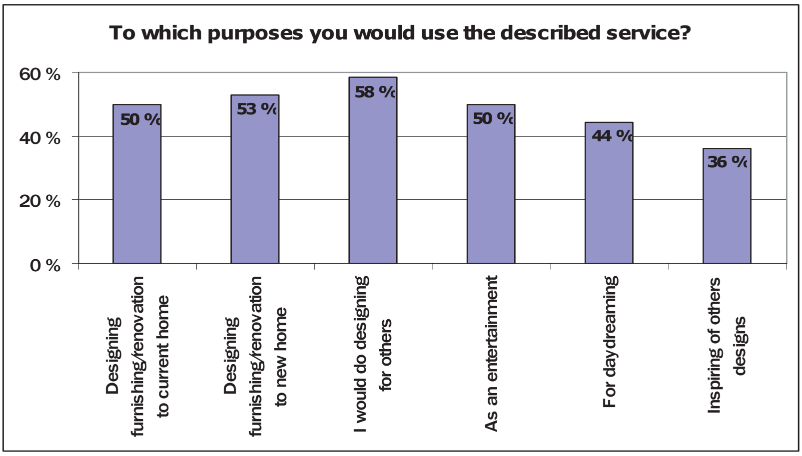


Figure 8. Pro-users would use this kind of service for several purposes.

Implementation of the Co-creation Sessions and Interviews

The co-creation sessions and interviews focused on augmented reality interior design service. However, we did not limit ideating strictly to augmented reality, but considered also other closely related technologies e.g. diminished reality and mixed reality features.

Implementation of Co-Creation Sessions

We organized six co-creation sessions; all five consumers participated individual co-creation sessions and the two interior designers participated a joint session. The sessions were carried out by same researcher and they lasted 1–1.5 hours.

The co-creation sessions consisted of three parts:

- scenarios, discussion of potential use cases of the technology, and first impressions
- experimenting with as existing AR interior design service and its reflections,
- personal opinions and preferences, and overall comments.

As the augmented reality concept is relatively new in consumer applications and therefore unknown for larger audience, the researcher presented shortly four scenarios of using virtual and augmented reality interior design service for the consumers. Apart from scenarios used in the surveys, an additional scenario using AR for renovation was presented. Besides, participant saw a short video illustrating use of AR interior design service. Thereafter, we collected participants' first impressions on AR interior design service and discussed how realistic they considered the presented scenarios. The interior designers were familiar with the AR concept, and no introduction to the subject was needed.

In the AR renovating scenario family is considering to buy a new home, but the one they are interested in needs some renovating so they test different materials, decorations, and furniture using AR renovation service before making purchasing decision.

In the second part, the researcher used together with the participant(s) a publicly available AR interior design application to catalyze discussion. The participants were instructed to take images of their home beforehand, and in case they had not done so, we took images in the beginning of the session or used sample images. We used images of participant's own living room in four consumer session and in other sessions we used sample images. During the second part, we discussed following themes: desired functionalities, potential or actual problems, naturalness of the combination of the real and virtual.

The consumers had no prior experience regarding augmented reality, but then the use of an actual system concretized the users what AR means. The researcher was operating the application; this was to prevent usability issues and technical limitations of the specific system to affect users' opinions on such services in general. We emphasized that the participant should think things that she wanted to do and not whether the desired functionality is technically possible.

In the third part, the participant was encouraged to make some conclusions and we discussed following themes: would they use this kind of system when buying a new house, purchasing items through the system and linking to a web store, the most important features of the system (when buying a new home/renovating/making interior design in current home), sharing the designs, what kind of items to test virtually, any other comments.

During the exploration of the AR interior design service the participants spontaneously came up with many of the themes of the third part, and those theme were discussed then.

The participants of co-creation sessions were 30-50 years old females.

Implementation of the Interviews

To understand the business factors affecting the service and its functionalities, we interviewed a professional interior designer having experience in using AR software in interior design, a representative of a furniture retailer, a representative of a company providing interior design on the Internet and a representative of a company providing an AR interior design Web platform. These are all representatives of value chain of AR interior design service presented earlier in Figure 3.

Interviews were carried out as individual focused interviews. Focused interview is a semi-structured method, which means that some of the features of the interview, for example the focus and the themes that are of interest, are decided beforehand by the interviewer. The method has features from the unstructured interviewing, for example the objective is to understand respondents' point of view more than make generalisations of their actions. (Hirsjärvi & Hurme 2001, Fontana &Frey 2005).

The themes discussed were (when applicable to interviewee's role): desired features of the AR interior design service, target users and potential users, future of the service, bottlenecks and technical challenges, user feedback, integration to other services, business prospects. With the interior designer we also discussed the themes of co-creation sessions.

Results of the Co-creation Sessions and Interviews

In the co-creation sessions, it appeared that professional users and consumers have different needs and expectations of interior design.

The consumers exploring with images of their own home seemed to ideate more, and wanted to test more interior designs, than those using sample images of a non-familiar room. This indicates that concretization of the concept using the user's own environment motivates the user, and also results in more concrete use scenarios. This finding is in line with the general concepts human-centered design (Maguire 2001).

The researcher operated the AR interior design system used during the co-creation session. This let the user to focus on ideas independent of the technical solution or interface. For example, the user might point the objects on the display and explain: *"I'd like to remove this piece of furniture"*, or *"I'd like to add here…"*. The users also got new ideas while doing something, especially when using images of their own home (Figure 9).

Figure 9. In the co-creation session, pictures from participants' own homes were augmented. This made the design process more concrete for the participants. For example, here a consumer compared whether to have one or two chairs, and came up with a new idea *"I would like to test some curtains, too"*.

Attributes of the Service

The consumers did not consider dimensional accuracy important, for them it is sufficient that the design *"looks realistic"*. They would use a traditional measuring tape before purchasing any items. In contrast, professional users share the opinion that the system should be very accurate; otherwise they would not be able to use it. The interior designers said that the interior design plan is supposed "*to show how the furniture fits in the physical space*" and therefore, the virtual objects should be restricted to room space, and the scale and dimensions of the AR system should be very accurate. Many current AR applications allow the user to move virtual objects through walls, and virtual objects may unintentionally overlap with other virtual or real furniture. The professional users saw this as a bottleneck for serious use.

The interior designers said that the color scheme and materials of the interior design plan are important. They expect that the colors and materials of 3D models should look natural and realistic. *"A customer buys a dream"* so the plan is more than the furniture *"it is the feeling that it creates"* and there the colors and materials are important.

The consumers wanted ready-made *"interior design atmospheres"* from which to start the design. Traditional interior design planning often starts by paging through images of different rooms. The AR system should provide a similar concept.

The consumers need a sophisticated database search, which enables search by color, style, size, price and other properties. The users mentioned that often people want, for example, a couch of a certain size (defined by size available), or they may have a limited budget and are interested in the prices. This is especially desirable in the consumer application. The search logic was not as important for the professional interior designers, as they know the product offering and remember most products by heart.

One issue came up in all discussions, no matter which role the interviewee or participant represented; the number and variety of available 3D models. It is essential to have a great number of pieces of furniture and decoration items as 3D models in the AR interior design system. The system should support the interior design, not restrict it. For a furniture retailer and interior designer working for certain retailer, the need is to have their whole product portfolio available. For interior designers not limited to certain brands or retailers, the need is *"all pieces of furniture they might want use in interior design otherwise"*. For professional users, the number of available products is very important. One of the interior designers said that she has 10 000 articles from which to select items for plans (+ different material options). This gives guidelines for the number of necessary 3D models in professional use.

The consumers would probably use an AR interior design application restricted to a brand or a retailer, but would also be interested in larger range of products. However, they wish not to have "infinite" number of choices, it would make the decision too difficult and too complicated. Besides furniture, interior design consist of smaller supplementary objects like curtains, plants and flowers, paintings, posters, photo frames, etc. The consumers and interior designers think that the 3D object library should contain a large number of these kinds of supplementary objects as well.

Consumers and interior designers emphasized that people have a personal history, they have *"old furniture with sentimental value"*, and most common situation is that they want to include part of this personal history to the interior design. Very seldom people want to renew all furniture at once, only in some new construction cases. Therefore, it is essential to consider existing furniture as a part of the design. Technically this would mean modeling of the existing future or representing it with a very similar one.

Both consumers and professional users thought that the system should be able to place virtual furniture behind existing furniture and to remove virtually existing furniture. The lack of these functionalities was seen by the professionals as a bottleneck for using AR in making interior design plans. *"It (AR) doesn't serve … because it requires an empty room. The system should be able to empty the room. Now, I can only add small items, like a lamp."*

Figure 10. Real interior design situations produced during the co-creation sessions led to concrete ideas; *"the system should be able to place the dresser behind the chair"* (above) and *"the system should be able to remove the existing furniture"* (below).

Some consumers were tolerant when the overlapping of real and virtual was small; *"I still get the idea"*, *"I can move the (disturbing) table aside"*. However, others wanted that the system would enable them to place virtual furniture behind existing furniture (Figure 10). In addition, they wanted the possibility to remove and move existing furniture virtually, especially heavy items, such as a piano or bookshelf, in order to test a new arrangement of furniture (Figure 10).

Those consumers, who had renovated their own homes, commented that "it would have been good to have this kind of service available". They would have used it "to test whether the family dining table fits in dining space" and "to test the wall colors and other materials". Here again, participants with firsthand experience of the subject were ideating more.

Interior designers and consumers mentioned virtual lighting as a very useful future feature. They saw an opportunity to visualize lighting effects using augmented and virtual reality. An ideal system would be able to show the space in realistic lighting in the evening, morning, winter, summer, etc. according to point of compass, windows' positions etc. Besides the ambient lighting, they see that it would also be useful to be able to model and visualize the lighting effect of different lamps e.g. the size of their spot light.

Consumers who would use an interior design program only once or occasionally are not willing to use time in learning how to use the system; it should be self-evident. Consumers would not bother to download or install anything. Whereas interior designers think that they would benefit from a more flexible system with more options and functionalities in professional use, they should be trained to exploit it. Things that they described were, for example, the possibility to assemble block-based furniture virtually, select materials, add virtual lights, remove existing furniture, and to add curtains, paintings, flowers, do some work to get more accurate measurements of the space.

In addition to planning renovation and interior design, consumers might use the AR interior design system for daydreaming and to brainstorming new ideas.

People see the importance of a good user experience on the first try as the most important factor affecting the success of an AR interior design system.

The interior designers told that many of their customers have difficulties to understand the 2D drawings; the use of AR will help them to understand the interior space better.

Interior designers reminded that interior design is a more than just the order of furniture, it is an atmosphere and customer buys a dream. Interior design is a creative process, and interior designers see a great challenge is preserving creativity when using technology.

Business Prospects and Bottlenecks

The scenarios used in user participation parts of the study were not presented to the commercial actors, yet they spontaneously presented ideas were very similar to the scenarios. The integration to several systems (Web store, social media, real estate marketing, etc.) is appealing, especially from the retailer's and system provider's viewpoint. The retailer would also be interested in functionalities that support marketing and enable different campaigns, blogs, design competitions, etc.

Most of the consumers said that they would not buy furniture without seeing it for real, but they might buy smaller decorative items, such as pillows and curtains from an integrated Web store.

The retailer notes a challenge in web store concept in ensuring that the product set the user selects is feasible i.e. if the user selects composes product from parts, it contains all parts needed for assembly.

Discussion

The study showed that there is a demand for easy-to-use design tools for consumers looking for a new apartment and also for professionals and pro-users working in the area of interior design.

Participatory design proved to be valuable; consumers, pro-users and professionals have different needs and requirements for the system. Involving the target user in the design process can be valuable for success of the service. Our approach combining different research methods and different user groups helped to find out the big picture of the consumer expectations, but led also more detailed information that can be applied in targeted application development.

Our study also brought up synergies and challenges between user needs and viable business model: For the pro-users and professionals integration to other services and social media is important, these features are also important from business point of view. On the other hand, users ask for large set of available model, yet it is challenging to create business ecosystem to support this. A cap between the user expectations and existing systems also came up: the users would like to search items by color, size and price and the current systems organize items by brands. User participation on the early stage of design process enables the service provider to adapt the system to this kind of requirements.

From the user perspective, the challenge of virtual home design services is often that many of them are quite difficult to use, especially for users without previous experience of these services. Some of the services may also demand heavy installation packages or complex registration systems, which may be an obstacle for users when starting to use the service.

As a conclusion, a service for consumers should concentrate on the user experience and the ease of use, whereas a service for professional users could be more complicated to enable all necessary functions.

The professional background of participants is one factor that could be taken into account in planning the methods for user participation. Ordinary users came up with more ideas by touching and trying out different things in the co-creation session. The use of participants' own pictures was essential to success. This technique made it possible to bring the concept closer to the everyday life of users, which has proved to be important for example in living labs and other user tests in real environments. Moreover, the broader consumer studies also reflected that there are differences in adopting new technologies and services among consumers, and most likely lead users and innovators would represent only views of small, technologically advanced user groups whose insights can't be generalized to apply to all users similarly. Otherwise, there is a risk for overestimating the consumers' willingness to adopt new technologies and services.

Professional users felt that it was easy to visualize interior designs in their minds; similarly they participated co-creation sessions in a more conceptual level. The starting point in co-creation with professionals was the comparison to their current working processes and habits rather than concrete examples like with ordinary users.

According to our research, it appears that all groups were able to produce new ideas, use their imagination, empathize with scenarios and talk about their ideas. When the service is designed for a large number of users, taking into consideration that the needs and motivations of the target users may be inconsistent, it is vital to bring in "the voice of the masses" to understand the varying needs and use contexts in everyday life.

Earlier research has pointed out the problem that when participating users are trained with earlier concepts and technology, it could restrict their imagination and capability to come up with fresh ideas. In our case, with a service that is relatively unknown to larger audience, this was not the case. Rather, the more examples were used, the more ideas users generated. The researcher facilitated the co-creation sessions in order to prevent the users to get stuck with the limitations of the current solution. We did not train participants about the actual technological solutions and constraints but concentrated on utilization possibilities. Actually, it was beneficial that the discussion was not limited to explicit definition of augmented reality. The discussion was open to all possible ideas about interacting with virtual and real elements in interior design.

In further work, we see that social media and online innovation tools combined with advanced modelling technologies could offer a fruitful innovation environment to develop the interior design concept further. Often, the lack of proper tools inhibits collaboration and ideation through online media (Antikainen, 2011). These online innovation communities could utilize and reward users' creativity and offer visual "do-it-yourself" tools for the collaboration and processing of ideas to bring in well-rounded insights.

References

1. Ainasoja, M., Kaasinen, E., Vulli, E., Reunanen, E., Hautala, R., Kulju, M. and Rytövuori, S. 2011. User involvement in service innovations – Four case studies. Proceedings of Conference on Mass Customization, Personalization and Co-Creation MCPC 2011 in San Francisco.
2. Alam, I. and Perry, C. 2002. A customer-oriented new service development process. Journal of services marketing **16**(6), pp. 515–534.
3. Alam, I. 2006. Removing the fuzziness from the fuzzy front-end of service innovations through customer interactions. Industrial Marketing Management **35**, pp. 468–480.
4. Antikainen, M. (2011) Facilitating customer involvement in collaborative innovation communities. Academic dissertation. Espoo, Finland: VTT Publications.
5. Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. and MacIntyre, B. 2001, "Recent Advances in Augmented Reality", IEEE Computer Graphics and Applications, vol. **21**, no. 6, pp. 34-47.
6. Azuma, R., Billinghurst, M., Klinker, G.."Editorial: Special Section on Mobile Augmented Reality". Computers and Graphics, 2011, issue 35, volume **4**, Pergamon Press, Inc, Elmsford, NY, USA. pp. 7-8.
7. Bødker, K., Kensing, F. and Simonsen, J. Participatory IT design: designing for business and workplace realities. MIT press, USA. 2004

8. Bratteteig, T. Design research in informatics. *Scandinavian Journal of Information Systems*, 2007, **19**(2): 65-74. 1.
9. Carbonell, P., Rodrígues-Escudero, A.I. and Pujari, D. 2009. Customer involvement in new service development: An examination of antecedents and outcomes. Journal of Product Innovation Management, **26**(5), pp. 536–550.
10. Fontana, A. and Frey, J. H. The Interview. From Neutral Stance to Political Involvement. In. Handbook of Qualitative Research. 3rd ed. Eds: N. K. Denzin and Y. S. Lincoln, Sage Publications, California, the US. 2005. pp. 695-727.
11. Franke, N., von Hippel, E., and Schreier, M. (2006). Finding commercially attractive user innovations: A test of lead-user theory. Journal of Product Innovation Management, **23**(4), 301-315.
12. Füller, J. 2006. Why consumers engage in virtual new product developments initiated by producers. Advances in Consumer Research, Vol. **33**, pp. 639–646.
13. Füller, J., Jawecki, G. and Mühlbacher, H. 2007. Innovation creation by online basketball communities. Journal of Business Research **60**, pp. 60–71.
14. Golparvar-Fard M, Peña-Mora F, Savarese S (2009) Application of D4AR – A 4-Dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication, ITcon Vol. 14, Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning , pg. 129-153.
15. Grönroos, C. 2000. Service management and marketing. A customer relationship management approach. Second edition. Chichester, Wiley.
16. Heiskanen, E., Hyvönen, K., Repo, P. and Saastamoinen, M. 2007. Käyttäjät tuotekehittäjinä (users as product developers). Teknologiakatsaus 216. Helsinki, Tekes. (In Finnish)
17. Henrysson, A.: Bringing augmented reality to mobile phones. Dissertations, Linköping Studies in Science and Technology. (2007)
18. Hirsjärvi, S. Hurme, H. Tutkimushaastattelu. Teemahaastattelun teoria ja käytäntö. Yliopistopaino Helsinki, Finland, 2001. pp. 34-48.
19. Holmquist, L.E.: User-Driven innovation in the Future Applications Lab. CHI 2004 Extended Abstracts on Human Factors in Computing Systems. ACM, New York (2004)
20. Hyvönen, K., Heiskanen, E., Repo, P., and Saastamoinen, M. 2007. Kuluttajat tuotekehittäjinä: Haasteita ja mahdollisuuksia. Kuluttajat kehittäjinä. miten asiakkaat vaikuttavat palvelumarkkinoilla. Helsinki, National Consumer Research Centre. Pp. 31–48. (In Finnish).
21. Kaasinen, E., Ainasoja, M., Vulli, E., Paavola, H., Hautala, R., Lehtonen, P. and Reunanen, E. 2010. User involvement in service innovations. VTT Research Notes 2552.
22. Kristensson, P., Gustafsson, A. and Archer, T. 2004. Harnessing the creative potential among users. Journal of Product Innovation Management **21**, pp. 4–14.
23. Kymäläinen, Tiina and Siltanen, Sanni. "Co-designing Novel Interior Design Service That Utilizes Augmented Reality, a Case Study", Second International Symposium on Communicability, Computer Graphics and Innovative Design for Interactive Systems. CCGIDIS 2012. Italy. July 5-6, 2012.
24. Lee, G.A.; Hyun Kang; Wookho Son, "MIRAGE: A Touch Screen based Mixed Reality Interface for Space Planning Applications," *Virtual Reality Conference, 2008. VR '08. IEEE* , vol., no., pp.273-274, 8-12 March 2008.
25. Lovelock, C., and Gummesson, E. 2004. Whither services marketing? In search of a new paradigm and fresh perspectives. Journal of Service Research, **7**(1), p. 20.
26. Lucero Vera, A., 2009. Co-designing interactive spaces for and with designers: supporting mood-board making. Vaajakoski, Finland. Gummerus Printing
27. Magnusson, P.R. 2009. Exploring the contributions of involving ordinary users in ideation of technology-based services. Journal of Product Innovation Management, **26**(5), pp. 578–593.
28. Magnusson, P.R., Matthing, J. & Kristensson, P. 2003. Managing user involvement in service innovation. Journal of Service Research **6**(2), pp. 111–124.
29. Martin Maguire. 2001. Methods to support human-centred design. Int. J. Hum.-Comput. Stud. **55**, 4 (October 2001), 587-634.

30. Menor, L.J., Tatikonda, M.V. and Sampson, S.E. 2002. New service development: areas for exploitation and exploration. Journal of Operations Management **20**, pp. 135–158.
31. Milgram, P., Takemura, H., Utsumi, A. and Kishino, F. 1994, "Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum", pp. 282.
32. Olsson T., Savisalo A., Hakkarainen M., Woodward C. ”User evaluation of mobile augmented reality in architectural planning”, eWork and eBusiness in Architecture, Engineering and Construction, Gudnason G. & Scherer R. (eds.), ECPPM 2012, Reykjavik, Island, Jul 25-27, 2012, pp. 733-740.
33. Pinto Seppä, I., Porkka, J., Valli, S., Siltanen, S., Lehtinen, E. and Teerimo, S. 2007. Dwelling renovation studio. Interactive tool for private residences renovation service. Espoo: VTT.
34. Rogers, E. M. 2003. Diffusion of innovations. Fifth Edition. New York: Free Press.
35. Saito, S.; Hiyama, A.; Tanikawa, T.; Hirose, M.; , "Indoor Marker-based Localization Using Coded Seamless Pattern for Interior Decoration," *Virtual Reality Conference, 2007. VR '07. IEEE* , vol., no., pp.67-74, 10-14 March 2007.
36. Sanders E. (2002) From User-Centered to participatory design approaches. Design and the social sciences, Taylor & Francis Books, Limited.
37. Sandstrom, S., Magnusson, P. and Kristensson, P. 2009. Increased understanding of service experiences through involving users in service development. European Journal of Innovation Management **12**(2), pp. 243–256.
38. Siltanen S. 2012 Theory and applications of marker-based augmented reality. VTT Science 3. Espoo. Finland.
39. Siltanen, S. and Woodward, C. 2006. Augmented interiors with digital camera images. Piekarski, W. (ed.). Seventh Australasian User Interface Conference (AUIC2006); CRPIT. ACS. Vol. 50. Ss. 33.
40. Sanders, E. and Stappers, P.J.,2008. Co-creation and the new landscapes of design. CoDesign, Volume **4**, Number 1, March 2008 , pp. 5-18(14).
41. Vargo, S.L. and Lusch, R.F. 2004. Evolving to a new dominant logic for marketing. Journal of Marketing 68 (January), pp. 1–17.
42. Von Hippel, E. 1986. Lead users: A source of novel product concepts. Management Science, **32**(7), pp. 791–805.
43. Von Hippel, E. 2005. Democratizing innovation. Cambridge, Mass., The MIT Press.
44. Von Hippel, E.: Lead Users: A source of novel product concepts. Management Science, **32**, 7, pp. 791-805. (1986)
45. Weber, M. 2011. Customer co-creation in Innovations. A protocol for innovating with end users. Doctoral Dissertation. Eindhoven University of Technology.
46. Woodward, C., Lahti J., R., J., Honkamaa, P., Hakkarainen, M., Jäppinen, J., Rainio, K., Siltanen, S. and Hyväkkä, J. 2007. Virtual and augmented reality in the Digitalo building project. International Journal of Design Sciences and Technology, Vol. **14**, No. No 1 (2007), pp. 23-40.

PAPER IV

Augmented reality enriches print media and revitalizes media business

ACM Computers in Entertainment. 16 pages. In print.

Augmented Reality Enriches Print Media and Revitalizes Media Business

Sanni Siltanen, Maiju Aikala, Sari Järvinen and Ville Valjus

VTT Technical Research Centre of Finland

Firstname.Secondname@vtt.fi (ä->a)

ABSTRACT

Print media is in a crisis; it is losing its share of advertising — its main source of income — to digital media. Our aim was to determine how augmented reality (AR) and other hybrid media solutions change print media's value chain and what kind of opportunities they offer. We studied both human and technical aspects and the critical challenges. We interviewed 20 actors of Finnish advertising and media business; they are very enthusiastic towards AR enriched interactive hybrid media. The user behavior measurability was found important. We present a sketch of the hybrid media value chain with the actors. We describe and discuss also selected AR applications. The AR technology is mature enough for mass market; the technical performance of smartphones is high enough for AR applications and also the penetration of smartphones is increasing rapidly. Our main conclusion is that hybrid media is essential in the future of print media.

INTRODUCTION

Major source of income in print media — newspapers and magazines — is advertising. The financial investment on advertising correlates strongly with the global economic situation; the value of media advertising dropped remarkably after year 2008 along with the global economy and it still has not recovered to the former level. Besides, the value of advertising in the print media is currently growing slower than the economic situation or investment in advertising in general would indicate. At the same time, the advertising in Internet is growing rapidly being already the third biggest advertising medium after newspaper and TV. (Antikainen & Kuusisto, 2012) Thus, the actors in print media are highly interested in finding ways how digital media could be used in print media to make it more desirable from advertisers' viewpoint.

Hybrid media can be seen as one solution to enrich the printed publication to allure advertisers. It is defined as the solution to link the printed product with the digital content. In its simplest form it means adding a tag or marker to a printed publication to be interpreted using a digital device such as a smartphone or tablet to access additional digital content or service. (Lindqvist et al., 2011)

Augmented reality (AR) technology enhances the real world by overlaying digital content and objects on top of user's view of the environment in real-time (Azuma, 1997). The AR services are currently used by means of camera-equipped devices: smartphones, tablets or PCs with webcam. The arrival of head-up-displays such as Google Goggles will open up new possibilities to AR service developers as the AR information can be presented proactively without user initiative. The AR applications rely on data provided by different sensors of the user device. Most often the solutions are based on computer vision technologies. The AR application detects the environment and tracks the movements of the device based on camera input. Mobile AR applications can also utilize several other sensors (GPS, digital compass, inertial sensors etc.) to deduce the location and orientation of the user. (Schmalstieg et al., 2011) The AR application knows the relative orientation of the user compared to real world and it can augment the user view inserting virtual objects with natural placement.

A rational approach in hybrid media is to combine AR with print media using specified objects or markers in the printed publication; the AR application detects pages of a magazine or special 2D barcodes, which are used to activate the digital augmentation objects. The printed markers also reveal to the user the existence of additional digital content to be provided using the AR application. In practice, the user scans a magazine with a smartphone that shows augmentation on display on top of the camera image. Alternatively, the user can show printed material to a web cam on PC environment and the augmentation is done on top of the web camera's image on the display or laptop's screen. The AR applications either update and download the content from a networked service or are stand-alone applications with fixed content.

The usage of AR applications with PCs equipped with web cameras is cumbersome. Fortunately the current development of mobile devices – smartphones and tablets - supports easier access to AR content and applications. The processing capacity of smartphones has increased, they support graphics features, and they have enough memory and bandwidth to support functionalities of AR applications. Moreover, tablets have large displays that support visual applications such as AR visualizations.

Mobile AR applications can be divided in two main categories: stand-alone applications and AR browsers such as Junaio, Wikitude and Layar. Mobile AR browsers use two main approaches; they augment geotagged information based on user's location or they use vision based system to detect objects and augment object-related data. Typically, the data is divided into information environments. (In Junaio, the environments are called "channels", in Wikitude "worlds" and in Layar "layers"). An environment is restricted to certain type of data, or a certain set of objects. The user can upload new environments and decide which information to see; in a location based service, e.g. tourist information or restaurants nearby, in a vision based system e.g. data related to pages of a magazine, or information about paintings in a museum.

Global smartphone markets

The total volume of smartphone sales globally continues to grow strongly. Figure 1 shows a forecast of global smartphone sales 2010-2015 (Frost & Sullivan, 2012). The global unit shipments are estimated to rise from 300 million to exceed 800 million by 2015. A trend in Finland (Gartner, 2011) shows, that from the four device categories: low-cost, basic, premium communication (smartphone) maximum price $300 and premium communication priced over $300, the cheaper smartphones interest the consumers most. It should be noted that operators in Finland enhance people to buy smartphones by combining the sale of a phone and a data connection. This trend observed in Finland appears to be quite typical as similar trends can be found in other countries as well.

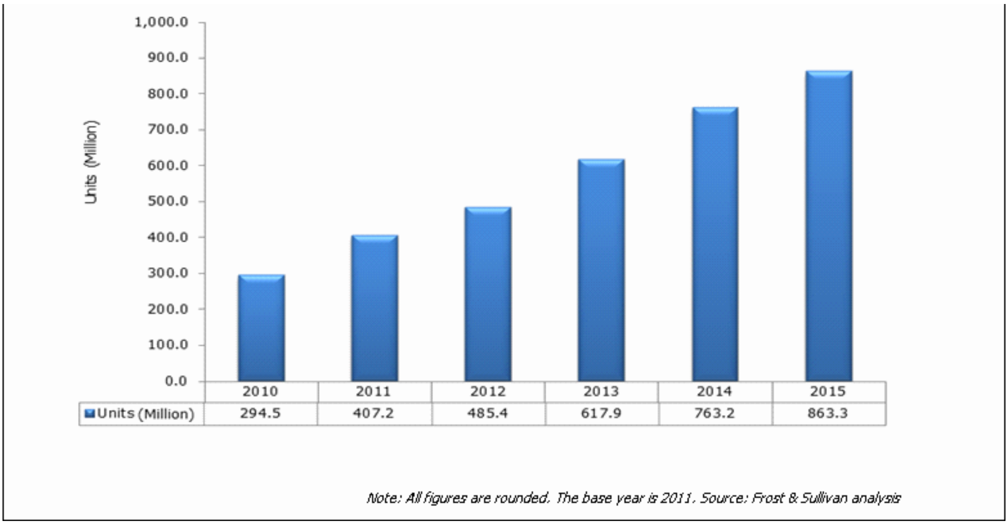
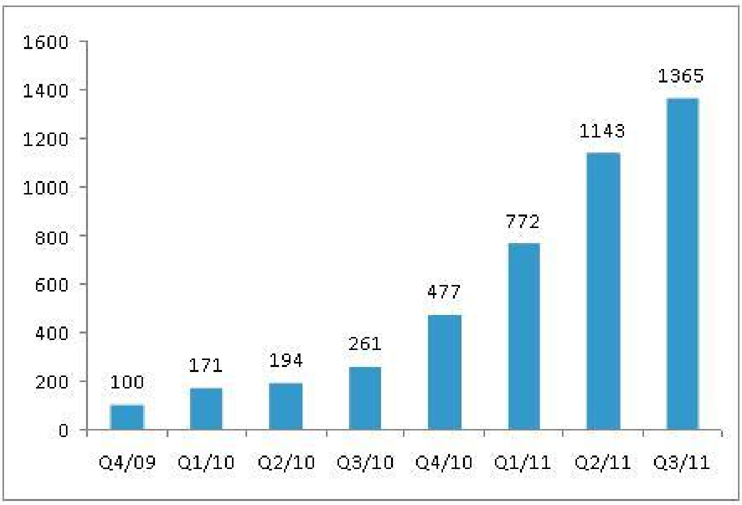


Figure 1. Forecast of global smartphone sales (2010-2015) (Frost & Sullivan, 2012).

Also the user behavior is changing. For example, mobile barcode activity is rapidly increasing, as shown in Figure 2 (3G Vision). Based on situation in the third quarter of 2010, the usage increased almost 500 per cents during one year. Interactivity gives an important additional value to advertisements. Besides advertisements 2D codes can be used also in editorial content.



(basis: Q4/09 = 100)

Figure 2. Global growth in mobile barcode usage Q4/2009 - Q3/2011 (3G Vision).

User acceptance

Together with the technology development, the usage of mobile applications has reached the majority in the technology acceptance model. The characteristics of the technology and use situation influence the technology acceptance process: what advantages new technology brings compared to other technologies, how complex or simple it is (Rogers, 2003; Compeau & Higgins, 1995). In addition, the assumed benefit and attitude towards use affect how users come to accept and use a technology, as well as voluntariness of use, experience, output quality, demonstrable results, perceived ease of use and social acceptance (Davis, 1989; Venkatesh & Davis, 2000).

The user acceptance of consumer level mobile nternet and location-aware information services is built on three factors: perceived value of the service, perceived ease of use and trust (Kaasinen, 2005). These three factors affect the intention to use a mobile service. Other studies show similar results concerning the user acceptance of different mobile services, e.g. the expected user experience of mobile AR services in a shopping center (Olsson et al., 2011). Therefore mobile hybrid media and AR services can be assumed to follow the user acceptance model of mobile services in general. With mobile services targeted at consumers, taking the services into use has often been considered to be a major obstacle to the user (Kaasinen, 2005).

Today the development of mobile application market places, such as App Store and Play Store, has made buying and installing mobile applications routine for many users. The overall mobile ecosystem supports mass market mobile applications, including AR hybrid media applications, and people have represented many individual AR and hybrid media applications. In addition, the availability of AR applications pre-installed on mobile devices decreases consumers’ threshold for taking them into use and thus supports the adoption of AR technology in the mass market. The latest Nokia Lumia smartphones have the City Lens application and Samsung Galaxy tablets the Layar AR browser installed on them, for example.

Markets are ready for AR

Augmented reality solutions have been used to enrich print media since 2009. Magazines and newspapers such as Esquire and The New York Times, for example have provided AR content. AR has been used in brand campaigns by Pepsi, Coca-Cola, Benetton, Calvin Klein, Ikea and others. Although the big brands have used augmented reality technology in their marketing, the AR business is still in its infancy.

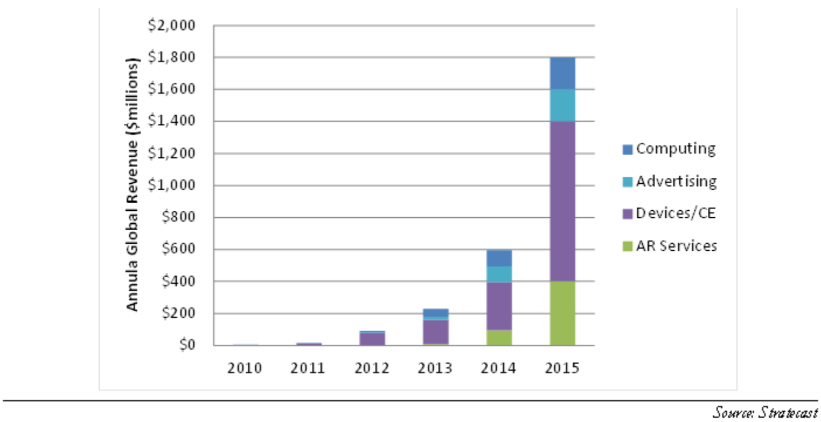


Figure 3 Global AR Market Projection 2010-2015 (Frost and Sullivan) (Jude, 2012).

Stratecast (Frost&Sullivan, 2012) projects that finally, starting at the end of 2012, total global revenues associated with AR technology and solutions will experience rapid growth. By 2015, the global market could exceed $1.8 billion. Most of the revenue, $1 billion, is expected to come from the devices and consumer electronics. The second largest share from AR Services ($400 million in 2015) and the remaining $400 million equally shared from AR related advertising and computing required to implement AR applications and services. (Jude, 2012)

The development of AR into a mass market technology is believed to depend on the brand owners. Juniper Research expects the industry and consumer adoption to lead in to mass retail and brand adoption of AR in advertisements and applications by 2015. In this stage there will be approximately 950 million AR capable handsets and more than 50 000 applications available for the mainstream smartphone audience. (Juniper, 2011)

Research aim

In this research, we studied the future framework of AR advertising in print media, beyond individual cases and demonstrations. Although this research concentrated on advertising it is clear that AR can be used to enrich editorial content as well. We also investigated the implementation specific issues of AR applications for advertising in print media and present selected use case implementations.

The aim of this study was to clarify, how the current actors in print products' value chain see the applicability of hybrid media and particularly augmented reality solutions in the print product of the future. Discussions about the future of the print media and how the augmented reality could change it were conducted with several professionals in the print product's value chain.

We interviewed 20 representatives of advertising and media business: brand owners, advertising agencies, media agency, publishing business and printing business (see Table 1). The focus was on the practical implementation of augmented reality solutions. The interviews were conducted at the end of 2010 and the data was analyzed 2011.

METHODOLOGY

Due to the objective of the study, i.e. understanding the current mindset towards AR in print media value chain, the qualitative research approach was utilized. We studied the subject in depth and across many organizations in order to find patterns in data. A qualitative research method is applicable, when the area being researched is not well known beforehand or the target is to reveal new and unexpected viewpoints from the area of interest (Gephart, 2004). The selection of the interviewees was based on their assumed ability to give new viewpoints on the subject. Companies in this study represent the different actors in different kinds of print products' value chains. The selected 12 organizations represent advertising, publishing and printing sectors. Thus, the sample gives an overview on the future of print media business in Finland. The interviewees are characterized in Table 1.

We used focused interview, which is a semi-structured method meaning that some of the features of the interview, for example the focus and the themes of interest, are decided beforehand by the interviewer. The method has features from the unstructured interviewing, for example the objective is to understand respondents' point of view more than make generalizations of their actions. (Bryman & Bell, 2011, Fontana & Frey, 2005) Both individual and focus group interviews were conducted. Representatives of same company were interviewed simultaneously.

Table 1. The interviewees.

Position in the	**Expertise**	**Number of**
Brand owner	Marketing	3
Brand owner	Product	3
Advertising	Digital content	1
Advertising	Digital content	1
Media agency	Media planner	1
Publisher	On-line	2
Publisher	Social media,	2
Publisher	Production	1
Publisher	Marketing	1
Printing	Sales and	1
Printing	Digital printing	2
Printing	Direct mail	2

At the beginning of the interviews, a brief introduction to augmented reality and the latest pilot applications in hybrid media field was given. The interviews were conducted as discussions starting from following themes:

Roadmap of print media and the role of AR in it: What is the role of print media and print advertising today and how it will change in next five years? What kind of opportunities and challenges AR will give to print media?

Target groups for AR applications: In what kind of print products will AR applications suit best? What target groups will be reached?

The new hybrid media value chain: How the print media value chain will change if AR applications will be integral part of print advertising? Who will take the leading role in AR production and who will make business out of it?

RESULTS

An interesting feature is that almost every interviewed party consider their own role and opportunities in the value chain stronger than the others (i.e. Media houses consider advertising agencies' role less important than advertising agencies themselves.) However, there is consensus of the components of the value chain, although the roles of the actors are not fixed.

AR advertisement and framework

So far, AR applications for print media have been separate applications created in separate projects, and often stand-alone applications that must be installed first. However, this is not how things should be. Our study shows that there is a need for a higher level system, where new content can be easily updated into the application, and where the authoring is independent of the end user's program. In this AR context, authoring means defining what is augmented where and how. For example, defining which 3D models are augmented on which pages, and defining also possible interactions, animation paths etc. for each augmented object.

With a framework, we refer to a whole system that defines all necessary parts of the AR advertising: how the content is authored and managed, how the augmented content is linked to the printed publication, how the applications are distributed etc.

In the sketched framework, the augmented reality advertisement consists of five different parts: printed advertisement, AR content, AR tool, AR viewer, and a terminal device (Figure 4). AR tool is an authoring tool, where the creator defines connection between digital content and printed publication. The intended terminal device affects to the content and functionalities of the AR. For example, tablets and smartphones have different graphics support.

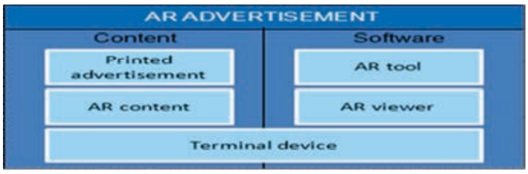


Figure 4 Components of AR advertisement

In a hybrid media solution, a vision-based approach would probably be the best solution; the application would detect pages of a magazine and show additional data linked to each page. As the users shun starting to use new applications, a browser type application would be better than a stand-alone. The information environments could be e.g. magazine wise, printing house wise or brand wise content i.e. once the environment is selected the user can see all additional content in a magazine, in all magazines of a printing house or all advertisements of a brand.

Similarly as with website editors, users can update and define content to a webpage without any knowledge about HTML or coding. An AR tool should enable definition of content, relations and interactions without any knowledge about detection technology, rendering or coding. Also AR researchers consider user-friendly authoring tool as one of the key issues, before AR will be used in massive scale (Schmalstig et al., 2011).

In further considerations, augmented reality was considered more like to be part of a broader hybrid media framework. In figure 5, we present the value chain of hybrid media solution for print media. In this framework, AR tool and AR viewer are substituted with hybrid media tool and viewer.

Target users

Advertising agencies, brand owners and media houses had congruent opinion with each other about early adopters of the technology. Teenagers and active young people who swap between different media were considered as the first potential target users of this kind of service. However, depending on the application area, all technology oriented people were seen as potential users. The challenge in a small market like Finland is the low actual number of users even when the penetration in the target group would be high. The other interviewees did not have clear opinion on target users.

Roles in the hybrid media value chain

Different printing houses see their role very differently. Traditionally printing house is at the end of value chain, they just print what customer wants. Digital printing house might take more active role in advancing hybrid media solutions. They might even provide all-in-one solution for their customers: Including everything from content, framework to personalized printing that enables personalized content and individualizing the users. Advertising agencies see their role as innovator and early adapters who market new technology for their customers i.e. brand owners.

Brand owners outsource campaign design and implementation for advertising agencies. They consider that they could own the framework i.e. brand wise application, but they hope for a bigger, standardized framework.

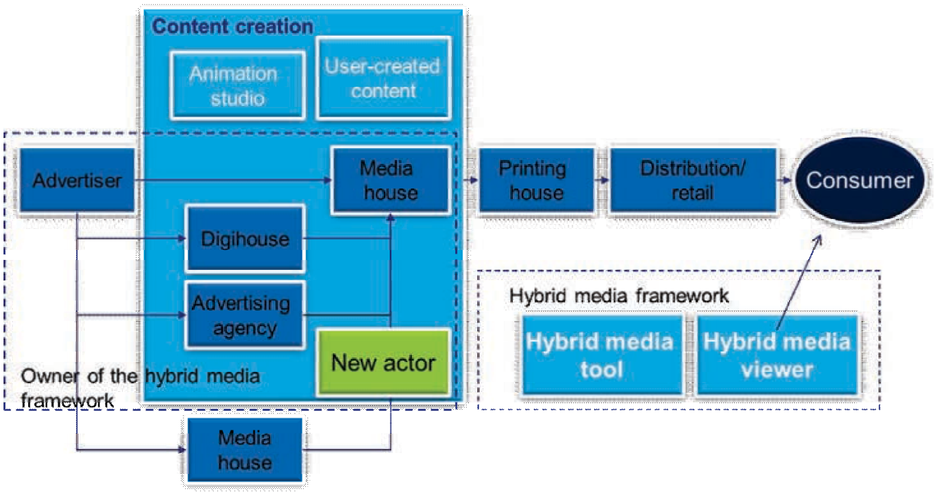


Figure 5. Value chain of hybrid media solution for printed publications.

Media houses' opinions on who is the driver of the technology vary; it can be a big international brand owner that has the possibilities to create a widely used system and thus manage the framework, or advertising and media agencies could ideate and apply AR in advertising for their customers. Some media houses see their own role as the framework creator and manager. They consider themselves as one of the brand owners.

Possible use cases

Augmented reality suits well for advertising because of its interactive and visual nature. One advertising agency considers campaign wise or event specific use as most interesting way to exploit AR. The other advertising agency and digital media house are into a widely used application. Media house would also prefer a widely used system or standard that they could exploit in all campaigns.

A new actor could provide a nationwide or international system. Creator of the framework can also be a software house who provides AR framework product. A new actor could also provide AR framework service, and may also master the framework.

User data and measurability

Media agency, as well as advertising agency, brand owner and media house, sees the possibility of measuring the user data especially important. It is of the utmost importance to get as much data from the users as possible: who uses the application, from which advertisement the user entered the Internet site, and how much time does he or she spend on the site. The data makes it possible to segment the users, and thus, target the message more precisely. For the media house, in addition to the above-mentioned factors, the reliable user data is one of their key assets.

AR APPLICATIONS -- IMPLEMENTATION ISSUES AND EXAMPLES

There are various new AR tools for easy and fast AR application development e.g. Layar Creator[1], Metaio Creator[2] and Aurasma Studio [3] currently available. These all can be used together with an AR browser (available for various platforms: iPhone, Android etc.) from the same technology provider meaning only one software installation process needed for the user to access all the AR applications created using a specific AR authoring tool and browser pair. AR applications can also be developed utilizing various AR software libraries such as ALVAR[4]. These libraries provide usually more features and thus enable more flexible and customized application development compared to the AR tools mentioned above, but on the other hand the applications are much more laborious to develop as there is more work to be done manually and also necessitate more specialized developers with AR technology know-how.

The AR applications require relatively high processing capacity of the target platform to execute e.g. the video analysis algorithms. Processing power has always been the strength of desktop computers as there is no need to make compromises between size of the device, the used components or the battery consumption. Thus, it has been possible to create AR applications that have only few limitations considering features such as the graphics quality and the complexity of 3D content. However, a disadvantage of traditional desktop applications is that they require separate installation procedure on every computer the user wants to run them on. Additionally, every operating system requires a dedicated version of the application to be developed and thus the portability of the application becomes difficult.

Adobe Flash technology enables developing portable cross-platform web-based AR applications. Flash based web applications can be executed without modifications on multiple operating systems and web browsers and they do not require each application to be separately installed. Flash applications are inferior to desktop applications when considering performance but with the latest generation of Adobe Flash (version 11) including the Stage3D API (application programming interface)[5]. Flash applications can nowadays handle much more complex 3D content than ever enabling also richer AR applications.

Downside in using Flash is that it is not properly supported by smartphone operating systems and thus it cannot currently be used on mobile devices. Currently the only feasible option for developing AR applications for smartphones is creating separate versions of the application for each platform. This brings forward the same problem as in desktop applications that the cross-platform support is much more laborious to achieve. A clear advantage in using a smartphone is that the device itself is much easier to carry around and use in different environments compared to desktop and laptop computers. While the processing power of

---

[1] http://www.layar.com

[2] http://www.metaio.com

[3] http://www.aurasma.com

[4] http://virtual.vtt.fi/virtual/proj2/multimedia/alvar/index.html

[5] http://www.adobe.com/devnet/flashplayer/stage3d.html

smartphones may never reach the level of ordinary computers their performance is constantly increasing and, on the other hand, the development of high-speed networking technologies together with cloud computing offer new possibilities, when the processing can be done in the cloud network instead of the smartphone (Kovachev, 2011).

Fairly new approach for solving the portability problem is to use HTML5. Current version of HTML5[6] contains a work in progress version of the MediaStream API. From the augmented reality point of view an interesting feature in it is the support for accessing device's local camera stream. Thus, HTML5 could be used for developing AR applications and as it is a wide-spread standard and is supported by a wide range of devices and browsers, it could be the future platform of hybrid-media augmented reality applications (Oberhofer et al., 2012).

Examples of AR applications for print media

As described earlier, AR applications can be stand-alone or they may download information dynamically, and they can be mobile or PC applications. Thus, they fall in four different main categories: web applications, stand-alone PC applications, stand-alone mobile applications and mobile browsers (Figure 6). In the following, we present examples of real AR applications used in Finnish print media. The example AR applications are all implemented using the ALVAR library by VTT.

Figure 6. AR application types.

Dibidogs AR advertisement was launched in Katso magazine 13-14/2010 (Figure 7). Dibidogs AR application was a stand-alone PC application that user was able to download from a given webpage. It was implemented in collaboration with Futurecode and Aller Media. In the application an augmented digital figure (the dog) appeared on the top of magazine page. Also the **Dibidogs children storybook** contained AR markers to enrich the user experience of the printed book with an accompanying stand-alone PC application.

[6] http://www.w3.org/TR/html5

Figure 7 Dibidogs AR advertisement and storybook.

The Sparkly mobile AR application was implemented in collaboration with Aller Media and Sinebrychoff (the brand owner of advertised Sparkly product). In the application a sparkling wine bottle appeared on top of magazine page, and the user was supposed to interact with the application and keep the bottle in balance for certain time to win a discount ticket. The mobile application for iPhone is available in App Store, and the printed add was in Elle Magazine 11/2012.[7] Readers valued the inspiration and connectedness that the use of the application offered (Seisto et al., 2012).

Figure 8 A screenshot from mobile AR advertising application "Sparkly".

Vares AR Flash application was developed in a commercial project for Aller Media, a leading entertainment and TV magazine publisher in Finland, and it was used for promoting two Finnish films, “Veijarit” and “Vares – Pahan suudelma”, with markers printed on the magazine Seiska (Figure 9). The purpose of the application was to combine conventional print media and digital media by adding interactivity to the magazine and thus enrich the reading experience (Valjus et al. 2012).

[7] www.vtt.fi/multimedia

Figure 9 A screenshot of application showing video and animation related to the movie "Veijarit" and a spread of the magazine Seiska containing markers related to the movie "Vares - Pahan suudelma".

Fujitsu AR application (Figure 10) was developed for iPhone and iPad and was designed to bring life to Fujitsu's annual review publication. The main feature of the application was to show videos related to the annual review using augmented reality. The printed publication contained two black-and-white markers and when the mobile device's camera was pointed towards one of the two markers a video was played back on top of the marker in the camera view.

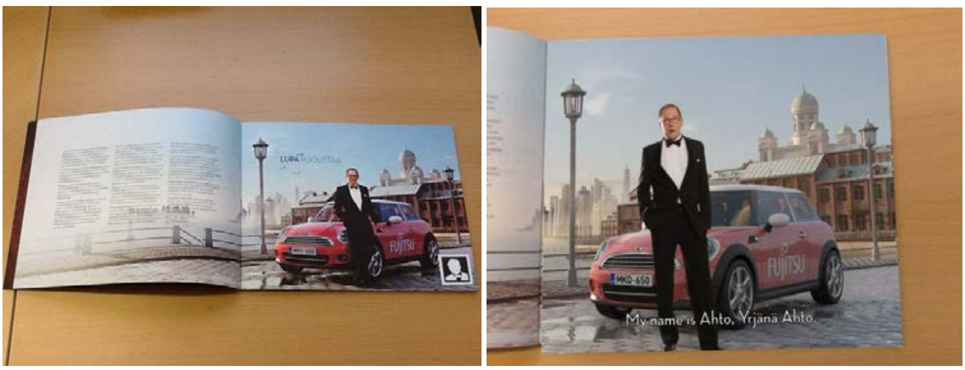


Figure 10 The Fujitsu annual review publication containing an AR marker and a screenshot of the application augmenting a video in the camera view.

Reflections on implementation issues

At the moment creation of AR applications is not cost-effective; the trouble of porting application to different platforms and the cost of content creation is high. This prevents applications targeted to small user groups — as often is the case in a small country such as Finland.

The trouble of getting the application into mobile market places (e.g. App Store) makes mobile AR browsers and web applications more desirable than stand-alone applications. However, web applications have limited graphics and other functionalities and have portability issues as discussed earlier. As for the browsers, the mobile application needs to be approved into mobile market place only once, and user need to install it only once, later the application can download new information dynamically. Nevertheless, this requires data connection, and slower connections do not support e.g. video streaming. The user experience of real time AR is poor if data connection fails. In the Fujitsu AR application, the videos are part of the stand-alone application, but then there is no way to update the video content.

On the other hand, stand-alone applications targeted on special device e.g. high-end tablets or PCs can utilize special features: fancy graphics and interactions — the very features that make AR appealing in the first place. For example, the Dibidogs AR book has good quality graphics features and interactivity. Mobile browsers lack these and often present simple augmentations.

At the moment authoring tools, the tools for creating AR applications in conceptual level, are limited; they offer only basic set of features and limited functionalities. In order to utilize strengths of AR such as interactivity, high-end visualizations and customized actions the application developer must use some of the software libraries and create the whole application, which is not cost effective. In addition, creation of interactive graphics requires a lot of manual work and is expensive.

All in all, implementation of AR applications requires often too much resource to be beneficial compared to other technologies. In order it to be widely used better and more flexible authoring tools needs be available and the cost of content creation (3D graphics and videos) needs to pressed down.

DISCUSSION AND CONCLUSIONS

The main conclusion of this study is that augmented reality should be part of a broader hybrid media solution. Augmented reality as such is often not enough, but it enriches a hybrid media solution. The same application could also provide other forms of digital information i.e. videos, links to web pages etc. Based on the interviews, the ease of use is the most important aspect. The system must be easy for the end-user, but also for the application provider. The ease of use is highlighted also in the literature of technology acceptance (Davis, 1989; Venkatesh & Davis, 2000; Kaasinen, 2005). In addition, most of the interviewees highlighted the importance of a general widely used system, and the difficulty of downloadable software and desire of ready installed software.

In PC environment, Flash-applications were considered the most important alternative as they function on a browser, supposing commonly used Flash-player plug-in is installed. However, HTML5 was not yet available at the time of the interviews and we believe it to offer even better alternative to dedicated AR applications or Flash-based implementations. The most important aspects are all factors that help surpassing the critical chasm of technology adoption.

So far it seems that the main reason for using AR applications stems from their novelty, instead of their practicality and relevance (Olsson & Salo, 2011). However, in the long run the personal relevance has an important role in the acceptance of AR technology (Olsson et al. 2011). Although web based AR applications provide interesting functionalities for electronic newspapers, print media would benefit more from mobile hybrid media solution. The user could enrich the reading experience with a mobile application independent of reading location.

The advancement of augmented reality technology and availability of simple AR tools for AR application development opens up new business opportunities in AR content and service creation as the AR service implementation does not anymore necessitate in-depth understanding of underlying technology. On the other hand, lack of standards slows down the adoption. Today several incompatible systems exist and different software is used in separate projects. On the other hand, as the AR and hybrid media domains are still changing, there is an opportunity to create a de-facto-standard and integral system, but it requires a big player, which is able to ensure enough critical mass. It might be Google with Google Glasses, or some other new player from outside of traditional print media value chain.

The situation is the same as with mobile services in general: several resources are needed and no single organization is able to possess all resources needed for typical mobile services offering or AR hybrid media application. (de Reuver et al., 2009) Thus, a value network for providing AR hybrid media services will be needed. However, some actors of the current print product value chain may take new roles as service integrators and manage an AR hybrid media framework. The task of the service integrator is to integrate basic products and services in the value network to offer combinations that match the individual customers' needs. In successful value networks the focus of the service integrator is on relationship process. (Heinrich et al., 2011) One of our interviewees sums up the scenario of the field as "*Hybrid media is part of the future print media*".

Importance of the user data

In the media market user information has a central role. First of all, the user data reveals who uses the media or service. This information can be utilized in targeting the message. Secondly, the user data might also give information about the media use habits and changes in them. This information can be utilized in planning the communication strategies. Hybrid media solutions bring a new dimension to collecting of user information. Today media houses collect information of how many magazines are sold, and how many visitors a webpage has, and from which webpage the visitor came. In case the user comes directly to the webpage typing the URL, or using a search engine, there is no indication of how user got the idea in the first place. Hybrid media solution can collect the information through which printed publication the user came to a webpage. In addition, application may collect data about time of the day and location where user reads something. Actors of print media believe that measurability of user actions increases advertisers' interest in print media – this is exactly what print media needs. An immersive mobile application may increase the time user spends with the application, plus collect this information. Naturally, privacy legislation sets limits for data collection.

Augmented reality brings interactivity to the reading experience

Augmented reality definitely changes the reading experience: AR brings interactivity to reading experience. Instead of an advertisement, the application can be an interesting service for the user, "*Interesting encounter with the product or brand*". For instance, with a mobile device, a printed furniture ad transforms into a digital service where the user can furnish own living room with virtual furniture using AR features of the application. What is more, the application can link the user directly to the electronic market place. How often do people see interesting URL in a print, but forgot it before next time sitting next to a computer, or are too lazy to start typing it on the smartphone? Hybrid media solution, where user points a page with a smartphone, and the link to the service is done automatically based on visual recognition, pass this gap and have a lot of potential.

Together with other engaging technologies, AR can be the trigger that gets the reader to use the service. AR and hybrid media is not limited to the advertisements; it can also enrich editorial matter and be part of the magazine's imago.

Future work

In this research we described the framework for AR hybrid media application, and the important roles in hybrid media value network. At this point we have not concentrated on the earning logics of different actors of the value network, or made in-depth analysis of the managerial issues concerning the value network. The next step would be constructing the business model for the AR hybrid media service.

The mass market adoption of AR enriched hybrid media services relies on many issues from device and communication technology to AR content production process development. However, the user has the most important role in the success. In order to have mass adoption of a hybrid media solution — or an AR application in particular — the users need to gain benefit from using application and the user experience needs to be gratifying. Should the users adopt it, then the interest of advertisers is guaranteed. As a next step, the value of AR usage for the use in the hybrid media applications should be studied in detail compared to other ways of combining print media with digital content.

REFERENCES

3G Vision http://www.i-nigma.com/pr29.html Accessed: 07.04.2014

Antikainen, H. & Kuusisto, O. Viestintäalan nykytila ja kehitystrendit 2012-2013. GT-raportti. VTT:n mediatekniikan asiantuntijapalvelu. Vol. 1. 2012. 43 p

Azuma, R.T. (1997) A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, vol. 6, no. 4, Aug. 1997, pp. 355-385.

Bryman, A., & Bell, E. (2011). Business Research Methods (3rd ed.). New York, NY: Oxford University Press.

Compeau, D.R. & Higgins, C.A. Application of Social Cognitive Theory to Training for Computer Skills. Information Systems Research 1995, Vol. 6, No. 2, pp. 118-143.

Davis, F.D. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly 1989, Vol. 13, No. 3, pp. 319-340.

de Reuver, M., Bouwman, H. & Haaker, T. Mobile business models: organizational and financial design issues that matter. Electron Markets 19, 2009, p. 3-13.

Fontana, A. & Frey, J. H., The Interview. From Neutral Stance to Political Involvement. In. Handbook of Qualitative Research. 3rd ed. Eds: N. K. Denzin and Y. S. Lincoln, Sage Publications, California, the US. 2005. pp. 695-727.

Frost & Sullivan (2012), Exploring the Evolution of Smartphone Vendors, published 23rd Aug 2012.

Gartner 2011 Forecast: Mobile Devices, Worldwide, 2008-2015. Gartner Market Statistics 2011.

Gephart, R. What is Qualitative Research and Why Is It Important?, Academy of Management Journal, 2004. Vol. 47. No. 4, pp. 454-462.

Jude, M.2012, Augmented Reality: The Virtual World Gets Real, Stratecast, Frost&Sullivan Connected Home, Vol. 2, No. 3.

Juniper Research (2011), Mobile Augmented Reality. Opportunities, Forecasts & Strategic Analysis 2011-2015.

Kaasinen, E. (2005) User acceptance of mobile services – value, ease of use, trust and ease of adoption. VTT Publications 566, Espoo 2005

Kovachev, D., Cao, Y. and Klamma, R. Mobile Cloud Computing: A Comparison of Application Models, CoRR, vol. abs/1107.4940, 2011.

Lindqvist, U., Federley, M., Hakola, L., Laukkanen, M., Mensonen, A. & Viljakainen, A. Hybrid Media on Packages. In Advances in Printing and Media Technology. Nils Enlund and Mladen Lovrecek (Eds.). Vol. 37. IARIGAI. Darmstadt, Germany, 2011, pp. 377-382

Oberhofer, C., Grubert, J., & Reitmayr, G. (2012). Natural feature tracking in JavaScript. Virtual Reality Short Papers and Posters (VRW), 2012 IEEE, 113-114.

Olsson, T. & Salo, M. (2011) Online User Survey on Current Mobile Augmented Reality Applications. In Proc. ISMAR 2011, 26-29 October, Basel, Switzerland. pp. 75-84.

Olsson, T., Lagerstam, E., Kärkkäinen T. & Väänänen-Vainio-Mattila, K. (2011) Expected user experience of mobile augmented reality services: a user study in the context of shopping centres. Pers Ubiquit Comput. 20 Dec. 2011

Rogers, E. Diffusion of Innovation. 5th Edition ed. New York, USA: The Free Press, 2003.

Schmalstieg, D., Langlotz, T. & Billinghurst, M., 2011. Augmented Reality 2.0. In G. Brunnett, S. Coquillart, & G. Welch, eds. *Virtual Realities*. Springer Vienna, pp. 13-37.

Seisto, A., Aikala, M. Vatrapu, R. & Kuula, T. (2012) Augmented Reality as a technology bringing interactivity to print products, 39th International Iarigai Conference, Sept 9-12, 2012, Ljubljana, Slovenia

Valjus, V., Järvinen, S., & Peltola, J. (2012) Web-based Augmented Reality Video Streaming for Marketing. Multimedia and Expo Workshops (ICMEW), 2012 IEEE International Conference on, 331-336.

Venkatesh, V. & Davis, F.D. A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. Management Science 2000, Vol. 46, No. 2, pp. 186-204

PAPER V

Multimodal user interface for augmented assembly

9th IEEE Workshop on Multimedia Signal Processing (MMSP). 1–3 October 2007, Crete. Pp. 78–81.

Multimodal User Interface for Augmented Assembly

Sanni Siltanen, Mika Hakkarainen, Otto Korkalo, Tapio Salonen, Juha Sääski, Charles Woodward
VTT Technical Research Centre of Finland
Espoo, Finland
firstname.lastname@vtt.fi

Theofanis Kannetis, Manolis Perakakis, Alexandros Potamianos
Department of Electronics and Computer Engineering
Technical University of Crete
Chania, Greece
{thkannetis, perak, potam}@telecom.tuc.gr

***Abstract*—In this paper, a multimodal system for augmented reality aided assembly work is designed and implemented. The multimodal interface allows for speech and gestural input. The system emulates a simplified assembly task in a factory. A 3D puzzle is used to study how to implement the augmented assembly system to a real setting in a factory. The system is used as a demonstrator and as a test-bed to evaluate different input modalities for augmented assembly setups. Preliminary system evaluation results are presented, the user experience is discussed, and some directions for future work are given.**

Keywords—multimodality;augmented reality, speech control, gesture control, visual feedback,assembly;

Topic area—Multimedia Communication

I. Introduction

In industrial production, the growing number of product variants, and the need for customized products, shorter life-cycles, smaller lot sizes and accelerated time to market have increased demands on production equipment and concepts. The production companies strive for increasing the performance of production and innovative approaches and technologies are required. One challenge is assembly work that requires skilled manpower to perform work tasks in a specified sequence with careful attention and particular skill. The use of AR (Augmented Reality) has been proposed as a solution to this challenge [5, 6, 7]. AR systems can combine human flexibility, intelligence and skills with the computing and memory capacity of a computer.

One of the main challenges is to the generate concepts for a human worker to operate in complex, short series or in a customized production factory environment. Each individual product may have a slightly different configuration: the order of assembling parts may vary for different products and/or the number of phases in the assembly line may be large. Often the human memory capacity is unable to handle all the required information. The traditional approach is to use assembly drawings (blueprints) and instruction manuals to check content of each work task. The disadvantage is that finding, reading and verifying this assembly information takes time and breaks the actual assembly work. An on site AR system can give the information automatically via a suitable device and the assembly work can be made more fluent and efficient. The challenge is to create a system with a natural user interface and use devices that do not interrupt the actual assembly work, e.g., allow for hand-busy interaction.

The potential of wearable augmented reality has been investigated at the early stages of this research [5,6,7,12], but the wearable AR systems have often been too heavy and big for industrial use. Wearable AR has been used more successfully for fun application and games [11]. However, the rapid development of mobile devices has lead to small devices with enough processing capacity and long lasting batteries to enable light-weight mobile AR systems. Recently PDAs, camera phones [8, 9] and mini PCs [13] have been successfully used in AR applications. At present, mobile augmented reality was listed as one of the ten most potential technologies in the annual MIT Technology Review [10].

Multimodal interfaces allow the user to interact with a computer using more than one input and/or output modes. Multiple modalities offer additional flexibility and make machines readily accessible to a population of naïve or handicapped users. In addition, appropriately designed multimodal interfaces that exploit synergies among modalities can improve efficiency as well as naturalness of interaction [14,15,16]. Most human-computer interfaces employ tactile (keyboard and mouse) input and graphical output. Recently, traditional graphical user interfaces have been augmented or redesigned to include natural language, speech, haptic and gestural input. Speech interfaces are natural and prove especially valuable for mobile application where the devices are too small to support efficient and convenient tactile interaction. This is also true for eyes-busy and/or hands-busy interaction where graphical user interfaces with tactile input are disruptive to the user's task.

In this work, we focus on augmented/virtual reality interfaces and investigate the use of spoken language and gestures as an alternative mode of input for an assembly task [1]. This is a hand-busy, eye-busy interaction and the use of tactile input, e.g., keyboard, to command and control the application is both unnatural and inefficient. Our goal is to investigate if the use of a multimodal spoken dialogue and gestural interface to control an AR application enhances the user experience in terms of efficiency and user satisfaction.

II. PROPOSED METHOD

In this evaluation phase we use a simplified assembly task that simulates a real assembly work. The task is to put 3D parts in a puzzle box (see Fig 1). The user follows instructions and puts piece-by-piece desired parts according to augmented instructions at the right place and in the right order. The parts fit in only if assembled in the right way and order. For system development, this task has various advantages compared to real assembly task. First this set is cheap, portable and adjustments and changes are easy to make. Yet the task is real-enough and the actual devices are used (HDM, camera, etc). With this simplified task we can test different input and output modalities, the robustness of the augmented system and get valuable feedback for designing the actual factory tasks. We use a modified version of ARToolKit [17] with some additional features and improvements for augmentation.

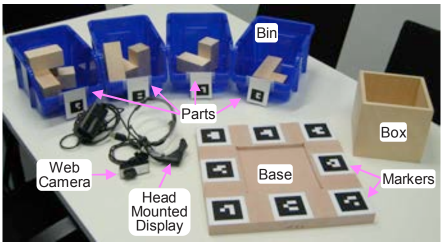


Figure 1: The overview of the demonstration system: the base, parts of assembly in bins, the box containing the parts, web camera and the head mounted display. The computing unit is not shown in this figure.

The assembly line worker often needs to wear safety glasses. We selected a very light weight display that can be attached to safety glasses to ensure minimum amount of parts/devices to be carried by the user. We used MicroOptical SV-3 PC Viewer as display that only weights less than 40 grams. The size of the display is 1cm x 2cm. A Logitech QuickCam for Notebooks Pro was also used. The camera was attached in the middle of the glasses so that the camera view and the user's view were consistent (Fig 2). In the real assembly work the wearable system should be as light weight as possible to enable real work. The interaction with the system should be natural and easy.

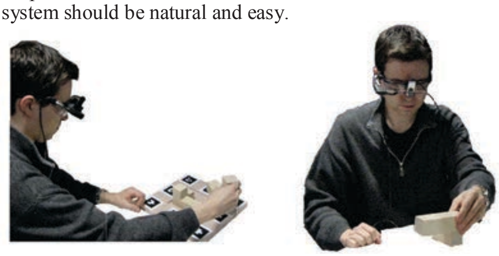


Figure 2: The user assembling the 3D puzzle box

For the first round of user evaluation we selected two potential input modalities: speech and gesture control. These were selected due to the hands-busy, eye-busy nature of the task and the limited additional hardware required (a small microphone). The architecture of the system allows adding modalities if required. In addition to augmented instruction, the system provides user feedback in textual and visual format on the display. No audio feedback was integrated in this version.

At startup the user selects the model to assemble (i.e. the correct instruction xml-file). After that the commands that the user can give to the system are to move forward to the next phase, move backward to the previous phase or start color calibration for the gesture recognition. The color calibration for gesture recognition can be started using speech input.

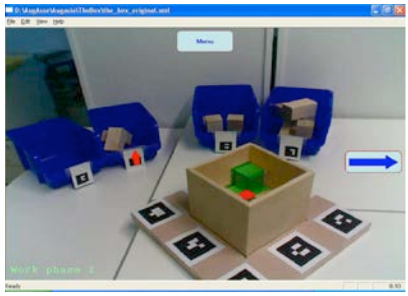


Figure 3: Augmented view: the right arrow indicates that "next phase" control has been detected

Gesture control

The system can be controlled using a head-up display (HUD)-like virtual menu. It consists of icons that can be selected by moving the hand over them. The menu has two states: active and inactive. In the inactive mode, the menu has an activation icon located at the center of the upper edge of the view. The user is able to activate the virtual menu by holding the hand on the activation area. As the menu is activated, two arrows are augmented to the view. The first arrow is located at the left upper corner, and by selecting it the user can move backwards in work phases. Similarly, the second arrow is located at the upper right corner, and it allows the user to jump to the next work phase. After a selection, the virtual menu disappears. If none of the icons is selected, the menu disappears after a small period of time. In practice, people tend to look at their hands while working on assembly task. As the camera is attached in the middle of the safety glasses pointing forwards, the hands appear most of the time in the center of the image. Thus, it is safe to place the menu items at the upper edge, and unintentional selections occur seldom

The hand detection algorithm has to be calibrated before usage. The procedure is carried out by asking the user to hold his hand at the calibration area (similar to menu icons). Then, the system acquires data for n frames. The hand detection is based on histogram back-projection presented in [4]. At the training phase, the hue histogram is constructed from the pixels located at the calibration area. As all the training data is obtained, the histogram is normalized. During usage, we use the value of the histogram as the probability of the pixel belonging to the object of interest. For each frame, we calculate the probability image of the pixels located in the area of menu elements. That is, we give every pixel a probability value of belonging to the tracked object (hand). As the probability image is constructed, we calculate the percentage of the object area covering the menu item. The value is used to make a decision whether the icon is activated or not. During the user evaluations, the limit was set to 50% in more than 7 out of 10 consecutive frames to apply selection. With the frame rate of 15 fps, this means that the user needs to hold his hand over the item for 0.7 seconds. The application allows us to change all the parameters, so the response time can be adjusted to meet the user preferences. We used skin color in user evaluations. Should the assembly worker use gloves, their color could be used instead.

Figure 4: The gesture regocnition in action.

Speech control

To incorporate speech input in the augmented reality system external automatic speech recognition (ASR) software is required. The speech recognition system operates in a client-server architecture: the controller (ASR client) collects audio data and sends them to the ASR server along with configuration parameters. The server then performs recognition and then passes on the results to the controller. The controller then passes on the (parsed) results to the application. Results and speech information can also be displayed graphical via a GUI interfaces. The overall system architecture is depicted in the next figure.

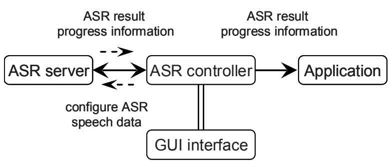


Figure 5: To decouple the application from the many details of handling speech input, the "ASR controller" is used. The GUI interface of the "ASR controller" allows to easily change various ASR parameters and fine tune the recognition process

The Sonic speech recognizer [2, 3] in its client-server mode, is used as "ASR server". In order to identify some simple commands (next, previous, next phase, previous phase etc.) tri-phone acoustic modes trained from males speakers are used and a simple grammar was written. Apart from the speech recognition, ASR server also keeps the log files that we used in the computation of the system word error rate (see evaluation). The "ASR controller", is used as the speech controller who establishes the communication between the system and the speech recognizer. It also allows to easily change various ASR parameters and fine tune the recognition process. Screenshots of the controller's GUI interface are shown next.

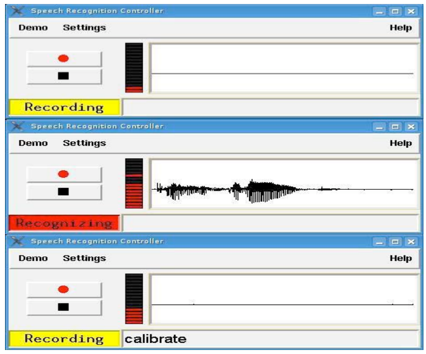


Figure 6: ASR controller GUI interface screenshots a) Recording speech b) Recognition in progress c) Recognition result.

First the user is connected to the ASR server using the controller GUI. In order to start the recognition process, the record button must be pushed. Once recording is started, voice activity detection is employed to determine user speech interaction (Fig 6a). A waveform or a spectrogram (depend on the user choice) is depicted along with a speech signal level meter for user feedback. Upon speech detection, audio data are sent to recognizer and the text "Recognizing" is shown in the left side of controller's GUI status bar (Fig 6b). Once recognition is finished, the recognized text is shown in the right side of the GUI status bar (Fig 6c). ASR controller acts as a proxy to the application by informing it of the recognition result and/or progress information which in turn can be shown by the application for user visual feedback. Finally some common configuration parameters can be easily adjusted using the "Settings" menu at any time (not shown here).

Feedback from the system

The assembly instructions are displayed on the HMD, thus one natural choice for feedback channel was to give visual and textual feedback on the same display. The virtual menu items are shown with red edges when hand is detected in the selection area (Fig 4). An arrow is also shown if the speech command is detected (Fig 3). A work phase count is shown at the lower left corner (Fig 3 and 4).

III. Experimental Results and Discussion

The system was evaluated by five novice users (two female, three male). Their experience of multimodal user interfaces varied from none to some and experience of virtual or augmented reality and previous use of data glasses/see-through displays varied. Two of them had no experience at all, one had tried data glasses before, and two of them were familiar with similar systems. The users tested the system in three experimental setups: first only with gesture or speech control, then only with the other control modality (gesture/speech) and lastly in truly multimodal mode (all modalities were allowed). In the third experiment, the users also calibrated the gesture recognition. The duration of the task did not depend on the modality used or on the order in which they used the different modalities. We used an acoustic model trained on male speakers (see speech control) that performed poorly with the non-native English speaking females, to investigate if speech recognition performance affected their choice of input modality. Both actual usage mode statistics were collected and the preferred modality was elicited via a questionnaire at the end of the experiments. As expected the recognized output was poor for female users and they preferred to use the gesture control over speech. The opposite was true for male users who had good speech recognition performance and preferred the speech control. In general, in the third phase, users preferred the modality that performed the best in the first two test phases. In the third phase gesture control was used successfully 9 times and speech control 13 times.

Some other users tried to solve the same task with printed instructions (on one page). For this simple task people who used the printed instructions were able to perform quicker than those using the augmented system. However some users were confused by the printed instructions, especially with the orientation and identity of one puzzle piece. This was not an issue for the augmented system where users were able to turn the base box and reveal the structure of the parts.

The users found the location of the virtual menu on the top of the image exhausting for long use, as the user needs to raise a hand to reach the virtual menu. (In fact, the users could also lower their sight to get the hand to appear on the top of the image over the virtual menu, but none of the test users used this feature).

All users found the feedback from the system insufficient. They were often unsure whether the system understood their command or not, and if the system really moved to the next work phase. The display contained a small text on the lower left corner containing the text "Work phase n", but the text was too small for the users to notify the change of the phase count. The system also displayed a right (left) arrow on the upper right (left) edge of the image when user gave the command "next phase" ("previous phase"). The users suggested that the arrow should have blinked or otherwise noticeable reacted to a recognized command. Also audio feedback (a beep) and progress bar were suggested.

The assembly instruction of each part was animated, the part moved from top of the base box downwards to the desired location in correct posture. One of the users suggested a pause feature to the animation, to be able to freeze the animation while comparing the posture of the part in the hand and the augmented part.

IV. Conclusion and Future Work

Comparing printed instructions to augmented instructions the difference was subtle in this simplified example, but all users shared the opinion that it may be useful for more practical assembly tasks (e.g. installing a digital-TV box, putting together furniture, etc.). Also the multimodal input interface was favorably judged by the users.

In an ongoing research project, we will focus on industrial case: assembly of a tractor accessory's power unit. In this case, the assembly worker is guided by virtual objects and visual assembly instructions. In the development of the industrial case, we will take into the consideration the results from this evaluation. We will concentrate on the robustness of input modes and improve on the multimodal output of the system, including the placement of the virtual menu.

Currently it is the user's responsibility to notice if he/she has performed the task correctly by browsing back- and forward in the instructions. In the future, we will use computer vision to recognize whether the user has put the right part in the right place and use the system also for worker training.

Acknowledgment

This work was supported by the EU-IST Muscle NoE.

References

[1] Bolt, R. Put-That-There : Voice and gesture at the graphics interface. Computer Graphics, 14(3): 262-270, 1980.

[2] Pellom, B. SONIC: The University of Colorado Continuous Speech Recognizer. Technical Repor TR-CSLR-2001-01, University of Colorado, March 2001.

[3] Pellom, B., Hacioglu Kadri. Recent Improvements in the CU SONIC ASR System for Noisy Speech: The SPINE Task. in Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Hong Kong, April, 2003.9.

[4] Swain, M. J. and Ballard, D. H. 1991. Color indexing. *Int. J. Comput. Vision* 7, 1 (Nov. 1991), 11-32.

[5] Azuma R., "A survey of augmented reality", Presence: Teleoperators and Virtual Environments 6, 4 (Aug 1997), pp. 355 385.

[6] Azuma R., Baillot Y., Behringer R., Feiner S., Julier S., MacIntyre B., "Recent advances in augmented reality", IEEE Computer Graphics and Applications 21, 6 (Nov/Dec 2001), pp. 3447.

[7] Bimber O. and Raskar R., "Modern Approaches to Augmented Reality", SIGGRAPH 2005, Course Notes on Spatial Augmented Reality, 86 pp.

[8] Henrysson, A., Billinghurst, N., Ollila, M., "Virtual object manipulation using a mobile phone", Proc. 15th International Conference on Artificial Reality and Telexistence (ICAT 2005), Dec 5th 8th,2005, Christchurch, New Zealand, pp. 164171.

[9] Rohs, M., "Marker-Based Embodied Interaction for Handheld Augmented Reality Games", Proceedings of the 3rd International Workshop on Pervasive Gaming Applications (PerGames) at PERVASIVE 2006, Dublin, Ireland, May 2006

[10] Jonietz, E., "Augmented Reality: Special Issue 10 Emerging Technologies 2007" , MIT Technology Review, March/April 2007.

[11] Haller,M., Billinghurst, M.,Thomas, B., Emerging Technologies of Augmented Reality, 2006, IGI Publishing, Hershey, PA, USA, pp.367-

[12] Thad,S. et al, Augmented Reality through Wearable Computing, Presence, Special Issue on Augmented Reality, 1997

[13] Honkamaa P., Siltanen S., Jäppinen J., Woodward C., Korkalo O., "Interactive outdoor mobile augmentation using markerless tracking and GPS." To appear in Proc. VRIC – Laval Virtual 2007.

[14] A. Potamianos et al, "Design principles and tools for multimodal dialog systems," in *Proc. ESCA Workshop Interact. Dialog. Multi-Modal Syst.*, (Kloster Irsee, Germany), June 1999.

[15] S. Oviatt et al, "Designing the User Interface for Multimodal Speech and Pen-based Gesture Applications: State-of-the-Art Systems and Future Research Directions", 2000.

[16] Sharon Oviatt , "Design Robust Multimodal Systems for Universal Access", Center for Human Computer Communication, Computer Science Department, Oregon Graduate Institute of Science & Technology, Proceedings of the EC/NSF workshop, 2001.

[17] ARToolKit: http://www.hitl.washington.edu/artoolkit/

PAPER VI

Augmented interiors with digital camera images

In: Piekarski, W. (Ed.) 7th Australasian User Interface Conference (AUIC); CRPIT. Vol. 50. ACS. Pp. 33–36.

Augmented Interiors with Digital Camera Images

Sanni Siltanen, Charles Woodward
VTT Information Technology
PO Box 1203, FI-02044 VTT, Finland
sanni.siltanen@vtt.fi, charles.woodward@vtt.fi

Abstract

In this paper, we present a system for Augmented Reality interior design based on digital images. The system can be used with an ordinary PC and a digital camera: no special equipment is required. Once placed in the image, virtual objects may be scaled, moved and rotated freely. In addition, the layout can be stored in file for later adjustment. We describe various user interface details and implementation issues, including a useful marker erasure method for general AR applications.

Keywords: User Interfaces, Augmented Reality, Virtual Furniture, Consumer Applications.

1 Introduction

We all know how difficult it is to choose the right sofa at the store, let alone taking it out and trying it at home. Thus, Augmented Reality (AR) technology has been proposed for interior design applications by several authors, see for example Koller et al. (1997). The related devices typically include data glasses hooked to a portable PC. A more light weight solution is to use a PDA, e.g. as proposed by Pasman and Woodward (2003). However, these devices are not commonly available for ordinary consumers.

In this paper, we present a solution for augmented interior design using just very basic home equipment, i.e. PC, digital camera and printer. A marker is placed on the floor to define the scale and coordinate system of the room. Subsequently the software system allows for a choice of virtual furniture to be placed into a room and viewed in a sequence of still images, taken from different view angles.

While a similar system has earlier been presented by the company, Augmented Solutions (2005), here we have added more functionality to the user interface and improved implementation issues, e.g. managing objects and projects, and adding lighting and shadows. Also, we present a simple method for removing the marker from the final images. This method has potential for being useful to many other AR applications too. Other issues covered include notes on Internet portal implementation of the system.

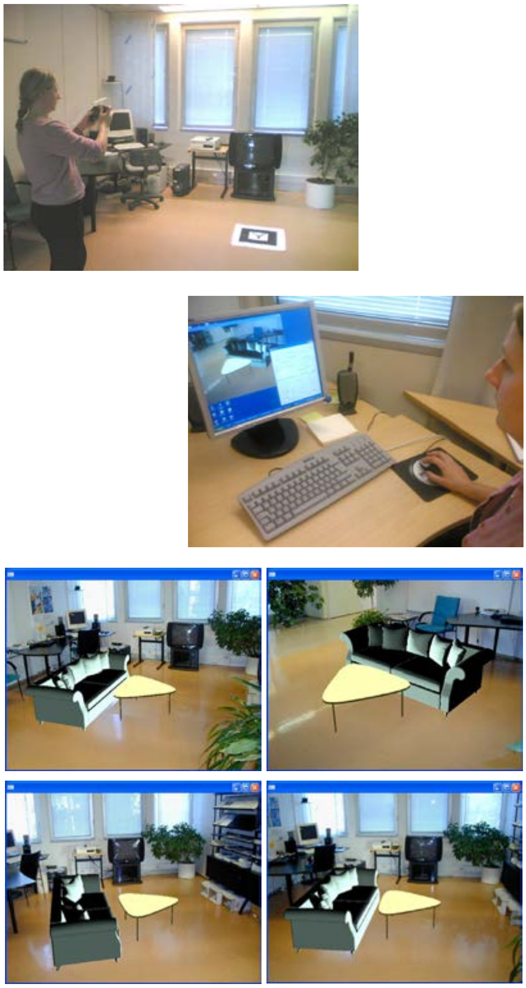


Figure 1: Images are taken, transferred to the computer and augmented with virtual furniture.

2 Operation and user interface

The operation of the system is described in following paragraphs (see Figure 1). First, the user prints out a marker that comes with the system. The style and size of the marker can be defined from the user interface in order to adapt it to the environment (viewing distance and size of the room). The marker is then placed on the floor of the room to be decorated.

The user walks along in the room and, on the way, takes a series of snapshot images with the digital camera. The images are uploaded to the PC using well established methods. Next, the furniture augmenting system is started.

Figure 2 shows the current user interface of the system. It includes functions for handling images, moving wrml-models and lights, defining marker properties and threshold values and for manipulating objects and lights. There are actually more options that would be in the real consumer application. Which of the options should be available depends on the eventual application.

The user may select different pieces of (virtual) furniture from the object list at left, then add, delete, change and hide them as required. Each piece of furniture first appears on the marker. The user may then move it to the desired position by dragging it with the mouse, or using the arrow/spin keys with adjustable step sizes. The arrow keys move the objects in the image always to the natural direction, e.g. the left arrow always moves the object to the left in the image. Many AR applications use fixed directions in marker coordinates. Accordingly, when looking from opposite direction, the object would move to unnatural direction. Our approach is more natural for the user, as he/she does not need to know anything about the marker coordinates.

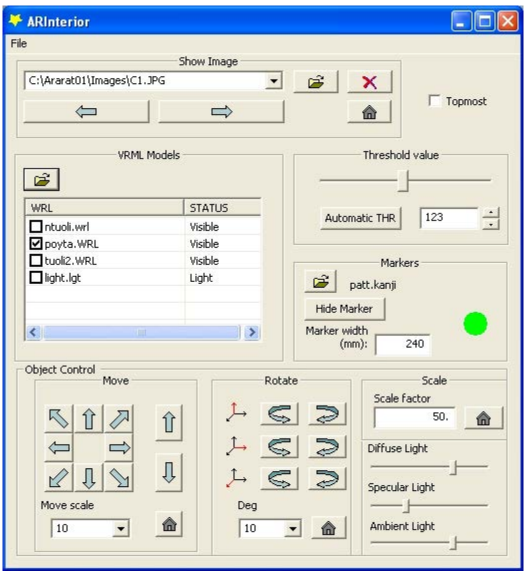


Figure 2: User interface of the system.

Once the virtual furniture has been arranged the user may scan through the digital images one by one from the top left pull-down menu, or by using the next/prev buttons. In each image, the virtual furniture stays in the relative position where it was placed before. The user may also save the augmented views in several image formats and print them out. In the near future, we intend to create a "pseudo video" function where the view point automatically moves through the set of augmented images. Also, we intend to enable looking at the virtual part of the scene from any view point, for example from the ceiling.

Our system is able to handle images of any (practical) size. While the image's size may be changed on screen as pleased, actual augmenting is performed on the original size images in order to obtain full resolution and antialiasing on the virtual model textures.

All the images and virtual models are loaded to the system dynamically. Furthermore, the state of the virtual furnishing application can be saved in a project file which can be loaded later as the user desires to continue with furnishing. Also, several project files can be combined together.

The marker detection may sometimes require adjusting the threshold value by which the markers are recognised. When required, the threshold value can be defined for each image separately. The system also keeps the threshold values in store between sessions. Traffic lights in the user interface indicate how well markers are identified. Green value means that the correct marker was found, orange that some marker was found but the marker ID is unsure, and red means that no marker was detected. This guided our test users to understand when the marker was poorly detectable in the images, or when the marker defined from the user interface was different from the one shown in the images. In future versions, we will add an auto threshold function to find an adequate threshold value automatically, but manual threshold adjusting may still be required in case the automatic method fails.

3 Implementation issues

We use the ARToolKit software (version 4.0) as the engine for marker detection and 3D rendering. Some modifications to the basic ARToolKit code were required to make it work more flexibly with still images instead of video, and to enable the marker definitions (pattern file name, physical size of the marker, etc.) through the user interface. Application programming involved first of all the transformation operations to release the virtual objects from the markers.

4 Erasing the marker from images

The appearance of the relatively large size marker can be somewhat disturbing in the augmented images. Therefore, we implemented a method for automatically erasing the marker from the images that are presented to the user; see Figure 3.

The method assumes the marker is placed on a relatively uniform colour background, such as room floors typically are. Thus, after we retrieve the marker corner points from ARToolKit, we expand them to cover also the marker's white surroundings, and fill in the interior pixels by bi-linear interpolation of pixels next to the white boundary of the marker.

The method has general value for many other AR applications too, as markers are most typically placed on uniform colour walls, tables, etc. The method is fast enough even for real-time implementation, it produces very good results in most cases, and in our application it is practically always better than showing the marker.

Figure 3: (Top) virtual object placed over the marker, (Middle) object moved and rotated to desired position (Bottom) marker erased and shadows added.

5 Lights and shadows

Light points can be inserted to the scene just like any other virtual object and, thereafter, manipulated with the object list. In the current implementation, we use a simple soft shadow algorithm where the shadows on the floor plane are presented using a semi-transparent alpha texture. The alpha texture is created by cumulating hard shadows based on a few jittered light points and smoothing the half-shadow (penumbra) area with an average filter. In the future, we might use a more sophisticated algorithm, like the one presented by Gibson et al. (2003).

Lights can be moved using the arrow keys just like the other objects. A red line from the marker centre to the light direction is shown for positioning aid (when the light is no more active in object list this line is not drawn). The user may change the intensity of the light source as well as the ambient lighting with the slider bars in the user interface. In this way, the brightness and shadows of the virtual objects can be adjusted to be near natural, in comparison to the eye-catchingly bright virtual objects that are seen in many other AR applications (see figure 4).

Figure 4: Without shadows, virtual objects seem to hang in the air, and if virtual lights are fixed, the brightness of objects is often unnatural (top). We augment virtual soft shadows underneath virtual objects and enable adjusting the virtual lights to the real room lighting (middle and bottom).

6 Increasing the accuracy

When using a single marker, the marker detection accuracy in the depth (z) component is much worse than in the image plane (x and y) components. This may cause the virtual objects to change their position when viewed from different directions. In a single image the object's position may look right while it is actually placed e.g. 5 cm above the floor. A second image from the side would then reveal the error and present the object in a drifted position.

Our near-future plan to improve on the depth accuracy (in single marker case) is to have an option indicating the camera's height relative to the floor/marker to the system. This would then enable numerically adjusting the detected marker position to match its known real world height. Typically, just a single height value would suffice for each user, assuming he/she stands straight when shooting the pictures.

Our system is able to use several markers, mainly for the purpose of covering large room areas but this can also be exploited to improve accuracy. Assuming the relative position of two or more markers in the real world is known (i.e. they are placed in measured positions), the detection accuracy can be improved using probability estimation of the detection error. Our method finds the most probable position and pose of the camera, based on the notions that (a) the detection error is biggest in the direction perpendicular to the camera, c.f. Pyökkimies (2002), (b) the orientation of the far away markers is more unsure than that of relatively near ones, and (c) the markers are actually all located in the same plane. This approach presents an improvement to the marker board idea used in ARToolkit which only relies on confidence values of each marker. The model matrix used in positioning of virtual objects is in a way a weighted average of those matrices calculated using separate markers.

7 Future work

Our implementation is still in its prototype stage, and we have various improvements in mind for the near future. Increasing the marker pose detection accuracy with single markers was already mentioned in the previous section. Adaptive marker thresholding, e.g. based on the method presented by Pintaric (2003), would be better than using fixed threshold value in whole image area, especially when several markers are to be detected from one image. Further, the marker erasure method could be improved by taking into account wider texture areas near the marker boundaries. Note that in our application where the marker is erased just once per image, even quite sophisticated image processing methods could be applied for this.

Currently, the walls of the room are ignored, and users may move objects unintentionally out of the room. A way to determine the wall coordinates would be having the user draw lines on the boundary between the walls and floor. Another possible solution is to find the floor by using region growing techniques based on the texture and colour of the floor. The marker is situated on the floor, thus we know from where to begin. Besides assuring the objects to be inside the room, finding the walls would also enable casting shadows on them.

The current implementation of the system is intended to serve as a desktop PC solution which the furniture manufacturer could deliver to customers by Internet download or on a product CD. However, the virtual model file sizes could be a problem with Internet download. Hence, another direction for future work is to develop the system into an Internet portal solution. It would operate on uploading images from the user's home to the web service, and downloading augmented images back, with all the 3D computation, tracking and virtual models residing on the server. Note that only overlay images of the virtual objects need to be downloaded (smaller than full images). Also, real-time interaction for positioning the furniture could be done locally using perspective approximations before refreshing the image.

8 Conclusions

We have presented an Augmented Reality interior design system that is operated with digital camera images. The system presents various improvements on user interface and presentation quality compared to earlier solutions. Most importantly, the system is easy to use. In particular, it can be operated using just ordinary PC and digital camera equipment. Also, the Internet portal implementation of our system is intended to be as straightforward as possible, and we hope to see our solutions applied in commercial use soon.

Numerous previously presented AR applications operate with real-time video. However, from user's point of view, it may be questioned how important real-time video actually is for interior design applications. Consumers are not ready to invest in e.g. data glasses, but many of them already have digital cameras available. The way people evaluate real furniture is looking from a few positions, and pausing for a moment to contemplate on what they see, in a way of still images. This is what we believe is best also for viewing of augmented interiors. Nevertheless, our system could easily be modified to process video clips too. Using e.g. the first video frame as the reference image to place the furniture, the rest follows from the discussion above.

9 Acknowledgements

We gratefully thank Mr. Mika Hakkarainen for general software engineering, Mr. Petri Honkamaa for the soft shadow implementation and Prof. Hirokazu Kato for his helpful advise with ARToolKit programming.

10 References

Augmented Solutions (2005): *Augmented Furniture Client*. http://www.ar-solutions.de/scripts/l_afc.php. Accessed 24 Aug 2005.

Gibson S., Cook J., Howard T., Hubbold R. (2003): "Rapid shadow generation in real-world lighting environments". In *Rendering Techniques 2003 (Proc. of the Eurographics Symposium on Rendering 2003)*, Leuven, Belgium.

Koller D., Klinker G., Rose E., Breen D., Whitaker R., Tuceryan M.(1997): "Real-time vision based camera tracking for augmented reality applications", *Proc. VRTT-97*, Lausanne, Switzerland, pp. 87-94.

Pasman W., Woodward C. (2003): "Implementation of an augmented reality system on a PDA", *Proc. ISMAR 2003*, Tokyo, Japan, pp. 276-277.

Pintaric (2003): "An adaptive thresholding algorithm for the Augmented Reality Toolkit", in *Proc. Second IEEE International Augmented Reality Toolkit Workshop (ART03)*, Tokyo, Japan.

Pyökkimies E.-P. (2002): *Detection of Object's Distance and Orientation*, Research report, VTT Information Technology. http://www.vtt.fi/multimedia/. Accessed 24 Aug 2005.

PAPER VII

Diminished reality for augmented reality interior design

Submitted to The Visual Computer, Springer, 18 pages.

Series title and number

VTT Science 87

Title	**Developing augmented reality solutions through user**
Author(s)	Sanni Siltanen
Abstract	Augmented reality (AR) technology merges digital information into the real world. It is an effective visualization method; AR enhances user's spatial perception skills and helps to understand spatial dimensions and relationships. It is beneficial for many professional application areas such as assembly, maintenance and repair. AR visualization helps to concretize building and construction projects and interior design plans – also for non-technically oriented people, who might otherwise have difficulties in understanding what the plans actually mean in the real context. Due to its interactive and immersive nature AR is applied for games and advertising as well. Although AR is proven to be a valuable visualization method it is not yet commonly used in beneficial consumer level applications. This work first finds out reasons for this and then focuses on developing AR towards wider use. The work is threefold: it considers human factors affecting adoption of the technology, economic factors affecting the viability of AR technology, and development of applications and technical solutions that support these factors. In this thesis user centric and participatory methods are used to find out reasons that hinder the use of AR, especially in interior design. The outcomes of the studies are manifold: desired features for AR services, bottlenecks preventing the use, user experience (UX) issues and business viability factors. A successful AR solution needs to have a viable business ecosystem besides a reliable technical framework. The presented application development in assembly guidance and interior design visualization considers UX factors and demonstrates the use of AR in the field of question. A serious bottleneck for using AR in interior design arises from a typical use situation; a consumer wants to redesign a room. The space where the interior design plan is made is not empty and augmentation does not look realistic when the new furniture is rendered on top of the existing furniture. This problem can be solved by using diminished reality, which means that the old furniture is removed digitally from the view. This work presents a diminished realty solution for AR interior design. A complete pipeline implementing diminished reality functionality is described. Algorithms and methods are developed to achieve real time high quality diminished reality functionality. The presented practical solution has a great effect for the whole AR interior design field, and enhances it towards real use. The possibilities of using AR are huge. In order to make beneficial AR solutions, researchers should be able to reveal the users' needs – both existing and emerging ones – and develop technology to fulfil those needs. This thesis demonstrates that this can be achieved by developing augmented reality solutions through user involvement.
ISBN, ISSN	ISBN 978-951-38-8248-8 (Soft back ed.) ISBN 978-951-38-8249-5 (URL: http://www.vtt.fi/publications/index.jsp) ISSN-L 2242-119X ISSN 2242-119X (Print) ISSN 2242-1203 (Online)
Date	May 2015
Language	English, Finnish abstract
Pages	134 p. + app. 117 p.
Name of the project	
Commissioned by	
Keywords	augmented reality, AR, diminished reality, user involvement, interior design
Publisher	VTT Technical Research Centre of Finland Ltd P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111

Julkaisun sarja ja numero

VTT Science 87

Nimeke	**Lisätyn todellisuuden kehitystyö ja käyttäjien osallistaminen**
Tekijä(t)	Sanni Siltanen
Tiivistelmä	Lisätty todellisuus (engl. Augmented Reality, AR) liittää digitaalista informaatiota todelliseen ympäristöön. Lisätty todellisuus on vaikuttava visualisointimenetelmä: se auttaa käyttäjää hahmottamaan tilaa ja ympäristön mittasuhteita ja esineiden välisiä yhteyksiä. Se on hyödyllinen monilla sovellusalueilla, esimerkiksi kokoonpano-, huolto- ja korjausopastuksessa. Lisätyllä todellisuudella tuotettu visualisointi auttaa konkretisoimaan rakennusprojekteja ja sisustussuunnitelmia – myös ihmisille, jotka eivät ole teknologisesti suuntautuneita ja joilla muutoin saattaisi olla ongelmia ymmärtää suunnitelmia ja niiden merkitystä käytännössä. Interaktiivisen ja mukaansatempaavan luonteensa vuoksi lisättyä todellisuutta hyödynnetään myös peleissä ja mainonnassa. Vaikka AR on osoittautunut toimivaksi ja hyödylliseksi visualisointimenetelmäksi, sitä ei vielä laajalti käytetä hyödyllisissä kuluttajasovelluksissa. Tässä työssä tutkitaan syitä vähäiseen hyödyntämiseen ja kehitetään lisättyä todellisuutta käyttäjän tarpeet huomioiden, jotta se saataisiin yleiseen käyttöön. Työssä on kolme osuutta: siinä tutkitaan inhimillisiä tekijöitä, jotka vaikuttavat teknologian omaksumiseen, ja liiketoimintaekosysteemiin liittyviä tekijöitä, jotka vaikuttavat teknologian elinkelpoisuuteen. Lisäksi kehitetään sovelluksia ja teknisiä ratkaisuja, jotka tukevat edellä löydettyjä tekijöitä. Tässä opinnäytteessä selvitetään käyttäjälähtöisten ja käyttäjiä osallistavien menetelmien avulla seikkoja, jotka hidastavat lisätyn todellisuuden hyödyntämistä erityisesti sisustussuunnittelussa. Tulokset ovat monitahoisia: lisättyä todellisuutta hyödyntävän palvelun toivottuja ominaisuuksia, hyödyntämistä estäviä pullonkauloja, käyttäjäkokemukseen liittyviä asioita sekä liiketoimintaekosysteemiin liittyviä asioita. Menestyvä AR-ratkaisu tarvitsee elinkelpoisen liiketoimintaekosysteemin luotettavan teknisen kehyksen lisäksi. Työssä esitetty kokoonpano-opastuksen ja sisustussuunnittelun visualisoinnin sovelluskehitys ottaa huomioon käyttäjäkokemukseen liittyviä tekijöitä sekä demonstroi lisätyn todellisuuden käyttöä näihin tarkoituksiin. Sisustussuunnittelun tyypillisessä käyttötilanteessa törmätään usein vakavaan pullonkaulaan. Kun kuluttaja haluaa uusia sisustuksen, on tilassa, johon suunnitelma tehdään, usein ennestään huonekaluja. Jos virtuaaliset huonekalut lisätään olemassa olevien huonekalujen päälle, lopputulos ei näytä realistiselta. Tämä ongelma voidaan ratkaista käyttämällä häivytettyä todellisuutta, mikä tarkoittaa sitä, että vanhat huonekalut poistetaan näkymästä digitaalisesti. Tässä työssä esitetään häivytetyn todellisuuden ratkaisu, joka tukee lisätyn todellisuuden käyttöä sisustussuunnittelussa. Työssä käydään läpi kaikki vaiheet häivytetyn todellisuuden toteuttamiseksi. Kehitettyjen algoritmien ja metodeiden avulla saavutetaan korkealaatuinen ja reaaliaikainen häivytetyn todellisuuden toiminnallisuus. Tässä esitetyllä käytännöllisellä ratkaisulla on suuri vaikutus lisätyn todellisuuden käyttöön sisustussuunnittelussa. Kehitetty ratkaisu on iso askel kohti laaja-alaista lisätyn todellisuuden käyttöä kuluttajasovelluksissa. Lisätyllä todellisuudella on paljon hyödyntämismahdollisuuksia. Jotta voidaan kehittää hyödyllisiä lisätyn todellisuuden sovelluksia, tutkijoiden on saatava selville käyttäjien tarpeet – sekä nykyiset että tulevat – ja kehitettävä teknologiaa, joka täyttää käyttäjien tarpeet. Tässä työssä osoitetaan, että tämä on mahdollista ottamalla käyttäjät mukaan lisätyn todellisuuden kehitystyöhön.
ISBN, ISSN	ISBN 978-951-38-8248-8 (nid.) ISBN 978-951-38-8249-5 (URL: http://www.vtt.fi/publications/index.jsp) ISSN-L 2242-119X ISSN 2242-119X (Painettu) ISSN 2242-1203 (Verkkojulkaisu)
Julkaisuaika	Toukokuu 2015
Kieli	Englanti, suomenkielinen tiivistelmä
Sivumäärä	134 s. + liitt. 117 s.
Projektin nimi	
Rahoittajat	
Avainsanat	augmented reality, AR, diminished reality, user involvement, interior design
Julkaisija	Teknologian tutkimuskeskus VTT Oy PL 1000, 02044 VTT, puh. 020 722 111

Developing augmented reality solutions through user involvement

Have you ever been in a furniture shop and wondered whether a couch fits in the space you have for it? Have you bought some interior decoration item – and realized at home that it doesn't fit the atmosphere? Or have you been frustrated when trying to understand the instructional pictures in an assembly manual for some gadget?

Augmented reality (AR) is a visualization technology that can help in the situations described above. It merges virtual objects into the user's view, and enhances spatial perception skills. Why isn't this technology widely utilized in everyday situations then? Are there still some technical bottlenecks that need to be solved before wide consumer-level use? Are there some business ecosystem factors that hinder AR applications from entering the consumer market? This work seeks answers to these questions.

We **involve users in the development process** and show that ordinary, non-technically oriented users can provide useful insight regarding emerging technologies such as AR. Different user-centred and participatory design methods are used to find out the factors hindering the widespread use of AR and user expectations regarding AR enhanced interior design services.

This work also describes **application development** to support wider use of AR and **algorithm development** to solve some critical bottlenecks, such as not having a way to remove existing furniture virtually. This thesis presents a solution for this kind of virtual removing functionality, aka *diminished reality*, which is an enabler for many AR applications.

ISBN 978-951-38-8248-8 (Soft back ed.)
ISBN 978-951-38-8249-5 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN-L 2242-119X
ISSN 2242-119X (Print)
ISSN 2242-1203 (Online)