

Minna Pakanen

VISUAL DESIGN EXAMPLES
IN THE EVALUATION OF
ANTICIPATED USER
EXPERIENCE AT THE EARLY
PHASES OF RESEARCH AND
DEVELOPMENT

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Abstract

User experience research has focused mainly on understanding user experiences during or directly after use. However, studies that focus on anticipated user experiences are scarce. Different methods and metrics have also been developed to measure user experience, but only a few are suitable for evaluating visual user interface design in an anticipated use situation. Moreover, these methods do not provide guidance on how to create suitable examples for research.

This thesis investigates how anticipated user experiences, needs, and wishes for visual user interface design can be studied in the early development phase. Furthermore, it investigates how visual design examples can be created and used in these studies as well as their benefits. To answer these questions, it was necessary to create and evaluate prototypes and visual design examples in the user early development phase user experience studies. The examples allowed the study of how interactive elements of user interfaces should be visually designed to draw users' attention to them. In addition, the thesis explains the means of increasing the visibility of an interactive object and the impact of its use context on its visual design.

A constructive design research approach is used in this thesis. The research material is compiled from the artifacts and results of the seven user studies. The main data collection and analysis methods are qualitative, supported with some quantitative methods.

The main contribution of this thesis is a practical EDE method for creating visual design examples and evaluating them in early development phase anticipated user experience studies focused on the visual design of a user interface. The second contribution of this thesis is user experience-based preliminary suggestions for the design of interactive elements within the studied user interfaces. The findings are useful for both practitioners and researchers dealing with user experience and visual user interface design.

Keywords: anticipated user experience, early development phase, user evaluation, user interfaces, visual design

Pakanen, Minna, Visuaaliset esimerkit ennakoidun käyttäjäkokemuksen evaluoinneissa tuotekehityksen alkuvaiheessa.

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Tiivistelmä

Käyttäjäkokeustutkimus on keskittynyt käyttäjien kokemuksiin varsinaisen käytön aikana tai heti sen jälkeen. Kiinnostus ennakoidun käyttäjäkokemuksen tutkimukseen ennen käyttötilannetta on herännyt vasta hiljattain. Käyttäjäkokeuksen arviointi- ja mittausmenetelmiä on kehitetty paljon, mutta vain harvat niistä sopivat visuaalisen käyttöliittymäsuunnittelun tutkimiseen ennakoidussa käyttötilanteessa. Menetelmät eivät myöskään opasta arviointiin sopivien visuaalisten esimerkkien suunnittelussa.

Tutkielmassa selvitetään, miten käyttäjien ennakoituja kokemuksia, tarpeita ja toiveita visuaalisesta käyttöliittymäsuunnittelusta voidaan tutkia tuotekehityksen alkuvaiheessa. Lisäksi selvitetään, kuinka visuaalisia esimerkkejä voidaan luoda ja käyttää alkuvaiheen ennakoidun käyttäjäkokemuksen arvioinneissa sekä pohditaan niiden etuja tutkimuksille. Jotta näihin kysymyksiin voidaan vastata, täytyi luoda prototyyppisiä ja visuaalisia esimerkkejä sekä arvioida niitä käyttäjätutkimuksissa. Esimerkkien avulla tutkitaan, miten vuorovaikutteisia käyttöliittymäelementtejä tulisi visuaalisesti esittää, jotta käyttäjä erottaisi ne muusta sisällöstä. Lisäksi selvitetään, miten elementin vuorovaikutteista ilmettä voitaisiin vahvistaa sekä arvioidaan sovellusympäristön vaikutusta elementin visuaaliseen esittämiseen.

Tutkimuksen lähestymistapa on konstrukttiivinen suunnittelun tutkimus. Aineisto muodostuu artefakteista ja seitsemän käyttäjäkokemustutkimuksen tuloksista. Tutkimusten tiedonkeruumenetelmät ja aineiston analyysimenetelmät ovat laadullisia. Lisämenetelminä on käytetty myös määrällisiä mittareita ja analyysimenetelmiä.

Tutkielman päätulos on käytännöllinen EDE-menetelmä, joka on tarkoitettu visuaalisten esimerkkien luontiin ja arviointiin alkuvaiheen ennakoiduissa käyttäjäkokemustutkimuksissa, jotka keskittyvät tuotteen visuaaliseen suunnitteluun. Tutkielman toinen tulos on käyttäjäkokemuspohjaiset alustavat suositukset tutkittujen käyttöliittymien vuorovaikutteisten elementtien visuaaliseen suunnitteluun. Tulokset palvelevat visuaalisen käyttöliittymäsuunnittelun tai käyttäjäkokemuksen parissa työskenteleviä tutkijoita ja teollisuuden ammatinharjoittajia.

Asiasanat: ennakoitu käyttäjäkokemus, käyttäjäevaluointi, käyttöliittymät, tuotekehityksen alkuvaihe, visuaalinen muotoilu

To my mother

Preface

The history of this thesis is the following. In the end of 2010, I was finalizing my master's thesis at the University of Lapland's Department of Industrial Design on user location indicators in mobile social media applications. The thesis was completed in collaboration with Dr. Jonna Häkkinen's team in the Nokia Research Center Oulu. While finalizing the thesis, I was hired as a project researcher in a multidisciplinary, practice-oriented research project called Chiru. The project was funded for three years by Tekes and two industry partners: Intel and Nokia. The research was carried out in the Center for Internet Excellence (CIE) at the University of Oulu. The project was divided into six sprints, which each lasted for six months. In each sprint, the topics changed slightly; therefore, it was possible to study different kinds of approaches during the three-year time period. My main responsibilities were the design for user experience as well as interaction, graphics, and service design of the prototypes. I also assisted senior user experience (UX) researcher Dr. Leena Arhipainen in planning and conducting the user studies.

The main aim of the project was to create new and compelling mobile user experiences of 3D virtual environment services and user interface designs. The research objectives, development platform, and devices that could be used in the research were settled together with the funders. The project focused on three main objectives. The first objective was to develop a hybrid 2D/3D paradigm for mobile devices with a strong focus on creating a positive user experience. The second objective was to adapt network virtual environment services for the mobile market. The third objective was to support the open-source community; thus, the development platform selected for the research was an open-source platform called realXtend (2015).

The tablet devices had just arrived on the market, so they were quite novel in the first user studies conducted in the project in early 2011. More and more different devices appeared on the market during the project, but the funders and the selected technical development platform set boundaries on the suitable tablet devices that could be used in the research. It was soon realized that it is not an easy task to get the realXtend platform working on any tablet, or even a touchscreen laptop. In addition, designing 3D UI concepts for tablet devices in the way that they can be operated directly by touch and not through traditional overlaid 2D UI, set its own challenge for the implementation work. Thus, we needed to find a way to study user experiences without functional prototypes because we needed user experience-based information for the visual and interaction design of 3D user interfaces and

services. Therefore, we needed to determine how to use non-functional prototypes in the evaluations in a way that can bring information on users' experiences, needs, and wishes for the design.

Additional challenge within the project was the continuous changing of topics every six months, which placed a considerable amount of pressure on the user experience and design work. Thus, many of the original publications of this thesis are focused on very detailed visual user interface design issues (V, VI, VII, & VIII). However, in one study presented in this thesis, it was possible to go deeper and attempt to understand wider visual user interface design issues with a larger design case (II). In the early phase of the Chiru project, the master's thesis was finalized and the publication written about it was published. This publication (V) offered an initial version of the EDE method, that is, how visual design examples can be created and used in early phase anticipated user experience studies. The publication got me so interested in the visual design aspects of the user interfaces that I wanted to do my PhD thesis on it. I started my PhD studies in Department of Information Processing Science (TOL) at University of Oulu Graduate School (UniOGS) in August 2012.

After the Chiru project ended in the end of September 2013, I was hired at Soul4Design Company for two-and-a-half-month research project. There the industry partner was Nokia Technologies. The aim of the project was to design a novel wearable device that utilizes deformability as a part of the interaction. This project was quite brief, yet very interesting and allowed the method to be tested in a different design case.

During this short research project, I received funding from Infotech Oulu Doctoral Program (DP) for two years for doctoral thesis work starting in the beginning of 2014. With this funding, I finalized one user experience study and wrote two publications about the studies conducted both in the Chiru (IV) and in the Soul4Design Company (III). I also completed most of the doctoral courses during this time. Most importantly, I was able to refine my thesis topic and research questions to combine all the different projects and studies in which the method was used. Publication I and this thesis are the results of this work.

Therefore, the road toward the final version of this PhD thesis was not as direct as one might have wished, but I think that it was also quite beneficial to obtain these varying views on the topic. Furthermore, these different design cases allowed me to focus the thesis more on the EDE method.

Oulu 13.11.2015

Minna Pakanen

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Oulu 13.11.2015

Minna Pakanen

List of abbreviations and definitions

2D	Two-dimensional
3D	Three-dimensional
AUX	Anticipated user experience
AXE	Anticipated experience evaluation
CVE	Collaborative virtual environment
CCS	Co-constructing stories
EDE	Explore, design, and evaluate
GUI	Graphical user interface
GPS	Global positioning system
GPU	Graphics processing unit
HCI	Human-computer interaction
KE	Kansei engineering
KESo	Kansei engineering software
NPD	New product development
OS	Operating system
PC	Personal computer
RtD	Research through design
TAM	Technology acceptance model
TUI	Tangible user interfaces
UCD	User-centered design
UI	User interface
UEs	User enactments
UX	User experience
VE	Virtual environment
ViDE	Visual design example
VR	Virtual reality
VW	Virtual world
WIMP	Windows, icons, menus, and pointers

List of original publications

This thesis is based on the following eight publications, which are cited throughout the text by their Roman numerals I–VIII. Publications are reprinted with permission from AMC (III–VI, VIII) and Springer (VII). Original publications are not included in the electronic version of the dissertation.

- I Pakanen M, Arhippainen L, & Kuutti K (2015) EDE: a method for creating visual design examples and evaluating them in early phase user experience studies. Manuscript.
- II Pakanen M, Arhippainen L, & Hickey S (2013) Designing for 3D User Experience in Tablet Context - Design and Early Phase User Evaluation of Four 3D GUIs. *International Journal on Advances in Intelligent Systems* 6 (3 & 4): 266–278.
- III Pakanen M, Colley A, Häkkinen J, Kildal J, & Lantz V (2014) Squeezy Bracelet: Designing a Wearable Communication Device for Tactile Interaction. *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*. New York NY, ACM: 305–314.
- IV Pakanen M & Arhippainen L (2014) User Experiences with Web-Based 3D Virtual Travel Destination Marketing Portals – The Need for Visual Indication of Interactive 3D Elements. *Proceedings of the 26th Australian Conference on Human-Computer Interaction*. New York NY, ACM: 430–439.
- V Pakanen M, Huhtala J, & Häkkinen J (2011) Location Visualization in Social Media Applications. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York NY, ACM: 2439–2442.
- VI Pakanen M, Arhippainen L, & Hickey S (2012). Design and evaluation of icons for 3D GUI on tablets. *Proceedings of the Academic MindTrek*. New York NY, ACM: 203-206.
- VII Pakanen M, Arhippainen L, Vatjus-Anttila J H, & Pakanen O-P (2013) Visual Indication While Sharing Items from a Private 3D Portal Room UI to Public Virtual Environments. In: Kotzé P, Marsden G, Lindgaard G, Wesson J, & Winckler M (eds) *INTERACT 2013. Lecture Notes in Computer Science 8120 (IV)*: 737–744.
- VIII Pakanen M, Arhippainen L, Hickey S, & Karhu A (2013) Visual Indication of Interactive 3D Elements in 3D Virtual Environments. *Proceedings of the Academic MindTrek*. New York NY, ACM: 1–4.

Authors' contributions

Paper I: The author was responsible for collecting and analyzing the data, developing the final version of the method, and writing the paper. The second and third authors provided comments, improvement suggestions, and feedback on the manuscript.

Paper II: The author was responsible for designing the examples for the study, analyzing the data, and writing the paper. The study design and data collection were shared responsibilities between the first and second authors. The second and third authors provided comments and feedback on the manuscript.

Paper III: The author was responsible for the design process, creating examples, and constructing physical prototypes with subcontractors. The author was also responsible for planning and conducting both user studies, the data collection, and the qualitative data analysis. These parts were also written by the author. The second author was responsible for the software design and technical development of the functional prototype and the quantitative data analysis. He was also responsible for writing those parts. The third author was responsible for writing related literature and the introduction sections. The first, second, and third authors shared the responsibilities of writing the abstract, conclusion, and discussion as well as editing the paper. The fourth and fifth authors provided feedback on the research process and comments on the paper.

Paper IV: The author was responsible for planning and conducting the study and the data collection in the second user study. The author was also responsible for the data analysis and the writing of the paper. The second author was responsible for planning and conducting the study and the data collection in the first user study and provided comments on the paper.

Paper V: The author was responsible for the design process and creating examples for the study, survey design, data collection, and the qualitative data analysis. The author was also responsible for writing the methods, study design, and results sections of the paper. The second author was responsible for the quantitative data analysis. The second and third authors supported the research process and were also responsible for writing the introduction and discussion. All authors shared the responsibility of editing the manuscript and writing the abstract and conclusion.

Paper VI: The author was responsible for designing examples for the user study, analyzing the data, and writing the paper. The study design and data collection were

joint responsibilities of the first and second authors. The second and third authors provided comments and feedback on the manuscript.

Paper VII: The author was responsible for designing examples for the user study, analyzing the data, and writing the paper. The study design, conduction of the study, and data collection were joint responsibilities of the first and second authors. The second author also provided comments on the manuscript. The third author was responsible for the technical design and development of the functional prototype. The fourth author was responsible for the quantitative analysis and provided comments on the manuscript.

Paper VIII: The author was responsible for designing the examples for the user study, analyzing the data, and writing the paper. The study design, conduction of the study, and data collection were joint responsibilities of the first and second authors. The third author was responsible for the technical design. The fourth author was responsible for the development of the functional prototype. The second and third authors provided comments on the manuscript.

Table of contents

Abstract	
Tiivistelmä	
Preface	9
Acknowledgements	11
List of abbreviations and definitions	13
List of original publications	15
Authors' contributions	17
Table of contents	19
1 Introduction	21
1.1 Scope of the research	24
1.2 Research questions	25
1.3 Contributions of the thesis	27
1.4 Overview of the thesis	28
2 Conceptual background and related research	29
2.1 Defining user experience	29
2.1.1 Experience	31
2.1.2 User experience	32
2.2 Temporality of user experience	33
2.2.1 Expectations	34
2.2.2 Anticipated user experience	35
2.3 Designing for user experience	36
2.3.1 Understanding the future user	38
2.3.2 Human-centered design processes	39
2.4 Evaluating user experiences	40
2.4.1 Early phase user experience studies	42
2.4.2 Early development phase AUX evaluation methods for investigating the visual design of an artifact	43
2.4.3 Prototypes in early development phase AUX studies	45
2.5 Visual user interface design	47
2.5.1 2D graphical user interface	48
2.5.2 Touch screen mobile user interfaces	49
2.5.3 3D user interface	50
2.5.4 Visual attention in 3D user interfaces	53
2.5.5 Tangible user interfaces	55

3 Empirical research methods and materials	59
3.1 Research approach	59
3.2 Focus and development phases of the studies	61
3.3 Artifacts	64
3.4 Study settings	66
3.5 Data collection methods	67
3.5.1 Survey	68
3.5.2 Laboratory studies	68
3.6 Participants	70
3.7 Data analysis methods	71
4 Results	73
4.1 The EDE method	74
4.1.1 Visual design examples	76
4.1.2 Benefits of visual design examples in AUX studies	77
4.2 Visual design of interactive content in the example UIs	78
4.2.1 Means for increasing the visibility of an object in studied UIs	78
4.2.2 Impact of the context on an object's visual design	81
5 Discussion	83
5.1 Theoretical and practical implications of the results	83
5.1.1 The EDE method allows AUXs and users' needs and wishes for UI design to be studied	84
5.1.2 The EDE method gives us a means for designing for interactivity	84
5.1.3 The EDE method allows for a mix of concrete examples plus conjecture about the future	87
5.1.4 The EDE method allows guided interaction with study participants	88
5.1.5 Objects can indicate their interactivity by their appearance	89
5.2 Limitations of the studies	91
5.2.1 Evaluation materials and subjects	92
5.2.2 Limitations of the user interface design findings	93
5.2.3 Reliability of the data collection and analysis methods	94
5.3 Future research opportunities	96
References	99
Original publications	115

1 Introduction

How a user feels when encountering a system, service, or product has interested human-computer interaction (HCI) researchers for over two decades. These subjective-, temporal-, and context-dependent feelings are called user experiences (UXs). The interest in UXs arose around the same time that another significant change happened within the HCI field: the increasing use of personal computers (PCs) in the late eighties. This change from work-oriented to leisure use of computers led to the interest in studying what makes people to want to use computers (Grudin 2006a). First, academia created usability engineering to allow the identification of the problematic moments of use to prevent errors. This change in use also meant that new interactive consumer products were constantly being designed; thus, there was a need to understand users' needs for both interaction and the design of the devices. (Kuutti 2009.) Thus, the first articles about usability engineering's inability to provide data for designing systems that people really want to use were written in the late 1980s (Carroll & Thomas 1988). After that, more researchers highlighted the need for a new approach that helps to understand holistic system use and users' hedonic needs for aesthetics (Alben 1996), pleasure (Jordan 1998), emotions (Desmet & Hekkert 2002, Norman 2004), enjoyment, and fun (Draper 1999, Monk *et al.* 2002, Blythe & Hassenzahl 2003) of the product, system, or service use. Thus, the user experience term was introduced to cover all these aspects. UX is agreed to mean users' subjective experiences that occur before, during, or after their interaction with a product, system or service (Pine & Gilmore 1998, Buchenau & Fulton Suri 2000, Forlizzi & Battarbee 2004, McCarthy & Wright 2004, Hassenzahl & Tractinsky 2006, Law *et al.* 2009, Arhippainen 2009, ISO 9041-210 2010, Roto *et al.* 2011).

The general interest of academia has been on user experiences that arise either during or after use of products (Vermeeren *et al.* 2010, Bargas-Avila & Hornbæk 2011). These momentary experiences are linked in single actions that a user has experienced (Luojus 2010). UX is also viewed as dynamic and temporal, thus endlessly changing a person's internal and emotional state (Hassenzahl & Tractinsky 2006, Arhippainen 2009, Vermeeren *et al.* 2010, Law & van Schaik 2010, Luojus 2010, Roto *et al.* 2011). In addition, experience is perceived to develop over time (Karapanos *et al.* 2009, Luojus 2010, Roto *et al.* 2011); therefore, the interest of academy in long-term UX has been aroused recently. According to Luojus (2010), long-term experience is reflective and created cumulatively over time from user experiences connected to certain activities guided by users' own

motives. Long-term studies are important when trying to understand why a product becomes meaningful in a person's life (Karapanos *et al.* 2009). However, the length of the evaluation period of long-term studies does not allow the delivery of UX data for the designers and developers in fast-paced projects when they need it; therefore, long-term studies are probably not the best for new product development (NPD)-oriented projects. The shift from the usability to the pleasurability of the product also increased the need to start studying the representational aspects of the designed products (Karjalainen 2004). Moreover, recent developments in technology have led to more and more technical interactive devices appearing on the market every day: in less than decade, we have witnessed a boom of smartphones, tablet devices, three-dimensional (3D) input- and output-enabling technologies, and most recently, health- and sport-related wearable technologies. Thus, there is a constant need for research related to understanding users' needs and wishes for new technological concepts and to choosing the best design alternative for further development as early in the development phase as possible (Stone *et al.* 2005). Therefore, the necessity to understand how users react to new technology and what their needs are for design of new technology has created a demand to understand UX prior to actual use.

This phenomenon is now being called anticipated user experience (AUX). There is no agreed-upon definition for AUX yet, but there are several different views on it. McCarthy and Wright (2004) see anticipation as an endless process suggesting something prior to the actual experience and that can happen before and during the aesthetic experience. According to Yogasara *et al.* (2011), AUX deals with expected experiences and feelings arising in imaginative interaction with a product. This definition is a bit risky, as it is based on the assumption that a person has to imagine both the product and the interaction with it. Desmet and Hekkert's (2007) definition is clearer: a non-physical interaction means anticipated, remembered, and fantasized usage, and a person can also imagine, anticipate, or fantasize possible consequences of interaction. Still it requires the subject to imagine without giving a concrete means to do so. Therefore, in this thesis, anticipated user experience is defined as *experiences, needs, and wishes that result from anticipated interaction with the concept of a product before the actual product exists.*

Early development phase AUX studies are not easy, and their challenges have been recognized in prior research. When anticipated user experience is studied, the results depend on the methods used. The difficulty of using early development phase assessment methods is that they should enable the evaluation of design ideas

(Buchenau & Fulton Suri 2000), but at the same time, they should be able to give a sense of experience before the actual artifact exists (Roto *et al.* 2011). Such methods should also permit the collection of altered feedback (Law 2011). Another factor affecting the results are the examples and prototypes used. The concepts in the presented example should be able to evoke people's dreams for the future (Sanders 2001, van den Hende 2010). In addition, examples should be concrete and sufficiently high quality to allow subjects to envision the concepts and prevent unwanted confusion (Kuutti *et al.* 2001, Gegner & Runonen 2012). They should also enable subjects to focus their attention on studied aspects in the design concepts (Lim & Stolterman 2008) and allow concept's key characteristics to be utilized and applied directly to the design (Law 2011).

Although visual design and aesthetic aspects of a product and its use have interested researchers, methods that enable AUXs to be studied with early development phase concept designs are scarce. Of the existing UX evaluation methods, only every fifth is suitable for studying AUX with concepts in the early development phase (Väänänen-Vainio-Mattila *et al.* 2008, Vermeeren *et al.* 2010). If the focus is on aesthetics or product appeal, even fewer methods exist (Bargas-Avila & Hornbæk 2011). There are only a few methods that can be used to investigate anticipated user experiences in the early development phase with visual examples: AXE (Anticipated eXperience Evaluation) (Gegner & Runonen 2012), Kansei Engineering Software (KESo) (Shütte 2006), paired comparison (Lavrakas 2008), and photo elicitation (Goodman *et al.* 2012). These methods are suitable for studying visual design, but none of them state how to create conceptual examples for the studies to be able to elicit data for the visual design. Thus, new methods that explain how to create visual examples and evaluate them in early phase studies are necessary. These methods should enable specific experiential and dynamic aspects of UX to be designed and evaluated (Väänänen-Vainio-Mattila & Wäljas 2009). They should also be practical, valid, reliable, repeatable, fast, lightweight, cost-efficient, applicable to various types of products, concept ideas, prototypes, different product lifecycle phases, and user groups (Väänänen-Vainio-Mattila *et al.* 2008). Thus, the main purpose of this thesis is to develop a practical method that allows AUX to be studied by creating consistent visual design examples and helping to evaluate them in early development phase studies.

1.1 Scope of the research

This thesis belongs under the large and multidisciplinary field of human-computer interaction. This discipline studies the design, implementation, and use of interactive computer systems and their impact on individuals, organizations, and society (Meyers *et al.* 1996). The thesis is focused under three sub-areas of HCI: UX, design, and evaluation, which are depicted in Fig. 1.

The first focus area of this thesis is user experience and its sub-area, AUX. UX research focuses on users' subjective experiences during different time spans: before, during, and after use of the product. UX is understood in this thesis as it is described in the ISO standard definition (ISO 9241-210 2010): human perceptions and reactions that are outcomes of the use or anticipated use of a system, service, or product. In this thesis, anticipated user experience can arise before actual use when person is envisioning the interaction with the product through given stimuli that can be textual and/or pictorial.

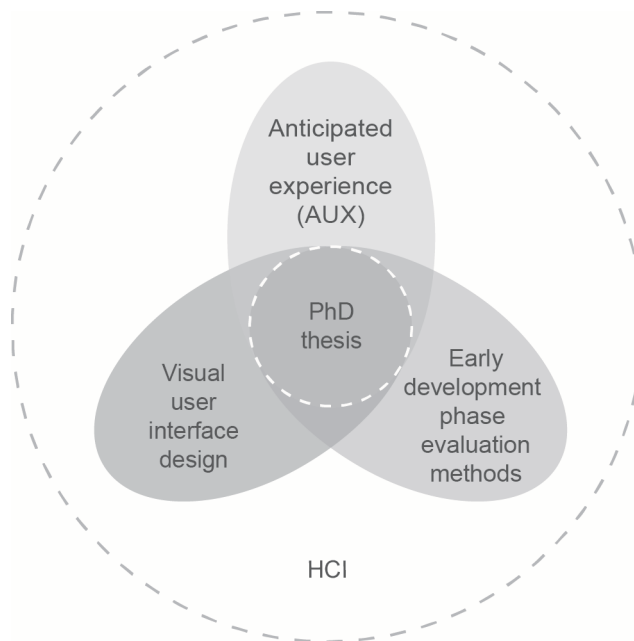


Fig. 1. Three focus areas of the thesis.

The second focus area of this thesis is early development phase evaluation methods. An early development phase in this thesis means the time period from the

exploratory design phase to when the concept has been selected for development and the development has begun. In this phase, fully functional prototypes do not exist yet; thus, the evaluation material is formed of non-functional or partially functional prototypes. Evaluation methods should allow the key features of the concept to be tested through non-functional prototypes and allow subjects to give feedback and comments as well as describe their needs for the design.

The third focus area of this thesis deals with visual user interface (UI) design. Although design is part of the HCI definition, design in this context is understood quite broadly, as it includes the technical, information architecture, interaction, information, UI navigation, and visual design of the systems and UIs (Garret 2002). The design in this thesis is understood to mean the artistic and aesthetic design of a UI. It also involves *the design for UX*, as well as visual, interaction, and service design. As in this thesis wearable technology is also studied, the visual user interface design deals also with the exterior design of an UI as well.

The focus areas of this thesis have several delimitations. Although usability, emotions, and aesthetics are an important part of UX and its research, they are not the focus here. This thesis also does not emphasize the quality of experience. Visual user interface design is investigated only with the artifacts that are described in the thesis. Even though 3D interaction is a vital part of 3D UIs, it is not studied here. This thesis does not focus on affordances, but recognizes that it deals with the visual design of interactive objects. Although technology acceptance research involves investigating how people will engage with technology in anticipated use situations, the author decided to leave technology acceptance out of the scope of the thesis, as it is well-established and extensively studied in information systems research (Venkatesh *et al.* 2003). Technology acceptance models allow individual reactions to use, intentions of use, or actual use of information technology to be studied (Venkatesh *et al.* 2003). One of the most used models is the technology acceptance model (TAM), which enables perceived usefulness and the ease of use in before-use situations to be studied (Venkatesh & Davis 2000). The author believes that the acceptance of technology is focused on the pragmatic side of the product concept choice, whereas AUX deals with the hedonic side as well.

1.2 Research questions

This thesis has two main goals. The first goal is to determine how AUXs and users' needs and wishes for visual design can be studied in the early development phase. The second is to provide design suggestions for the small and very detailed user

interface issues encountered during such studies and to evaluate and find answers to the first research question. The goals of the thesis are divided into two main research questions, both of which have two more detailed sub-questions:

1. How can anticipated user experiences and users', needs and wishes for visual user interface design be studied in the early development phase?
 - a) What kinds of visual design examples can be used and how can they be created?
 - b) What are the benefits of the visual design examples in the evaluation of anticipated user experience at the early phases of research and development?
2. How should interactive objects of studied user interfaces, both virtual and physical, be visually designed to effectively draw users' attention to them?
 - a) What are the means for increasing the visibility of an interactive object in the studied user interfaces?
 - b) What is the impact of the context of an object on its visual design in the studied user interfaces?

The answers to the research questions are formulated based on eight publications (Table 1). Publications V and I represent the initial (V) and final (I) versions of the EDE method that answers to the first research question. Publications II–III and V–VIII present the design cases in which the method was utilized in studies with different UI concepts and address the second research question, but also contribute knowledge on the use of the method for the first research question. Publication IV is a comparison study in which the method was not applied; thus, its main contribution is directed to second research questions.

Table 1. Publications and their contributions to the research questions.

	I	II	III	IV	V	VI	VII	VIII
RQ1	X	X	X		X	X	X	X
RQ1a	X	X	X		X	X	X	X
RQ1b	X	X	X			X	X	
RQ2		X	X	X	X	X	X	X
RQ2a			X	X		X	X	X
RQ2b		X	X	X	X	X	X	X

1.3 Contributions of the thesis

The thesis offers contributions for different audiences, both in academia and in industry in the field of user experience and visual user interface design. The main contribution of this thesis is a solution to the problem indicated in prior research that there are not enough early development phase AUX evaluation methods that enable users to understand, perceive, and evaluate future design. Therefore, the explore, design, and evaluate (EDE) method developed in this thesis (V, I) is a valuable contribution for both the UX practitioners and researchers dealing with visual UI design. The EDE method allows anticipated user experiences of the visual user interface design to be studied by creating examples and evaluating them in early development phase experiments. The method was utilized in six user studies with different focuses and design problems and compared to one study conducted without it. In the publications, the evaluation of the method is not explained extensively; thus, in publication I the method's suitability for different kinds of studies is presented by reflecting and interpreting UXs of the method in use in the studies conducted within the thesis projects. Based on versatile experience, the EDE method is perceived to be useful for purpose of AUX studies. An iterated version of the EDE method is presented in publication I with clarifications and guidance on how to use it in AUX studies.

In publications II, III, V, VI, VII, and VIII, the method is applied and tested with different kinds of design issues. Publications II and III present two studies in which the EDE method was applied in the concept phase to study larger visual user interface design issues, anticipated interaction, and to gain a more holistic understanding of AUXs and users' needs and wishes for the UI design. The contribution of these papers is that they demonstrate that the EDE method can be used in parallel with larger human-centered design processes for understanding AUXs more holistically with larger UI design issues.

Publications V, VI, VII, and VIII present studies in which the EDE method was utilized in studying smaller visual user interface design issues. These studies provided detailed data for the design of a certain object or UI feature. They also applied the EDE method and showed that it can be used to investigate small, detailed user interface issues with multiple comparable visual examples in the early development phase.

Publication IV presents two experiments conducted without the EDE method. These comparison studies confirmed the findings of publications VII and VIII by utilizing a fully functional prototype. Thus, these comparison experiments show

that the findings gained with the EDE method can be reliable, at least in this certain design case.

In addition, a more detailed contribution of this thesis is directed toward designers and developers of both virtual and physical UIs. In publications II–VII, visual user interface design issues were investigated. The findings of these studies indicated that there is a need for more comprehensive research on how interactive elements should be presented to users so that these elements visually show their interactivity. The findings related to these aspects should be seen as preliminary suggestions, as they need to be evaluated more thoroughly in later studies.

1.4 Overview of the thesis

In Chapter 2, the conceptual background of the thesis and the related research are presented. This chapter combines prior research on user experience and visual user interface design. In addition, the rationale for the research questions is provided.

In Chapter 3, empirical research methods and materials are presented. First, the chosen research approach, a combination of three constructive design research approaches, is explained. Then, the seven UX studies that were conducted during the thesis are presented. Next, the artifacts used in the experiments are described. The studies' focus, settings, development phase, and participants are also summarized. Likewise, the data collection and analysis methods are described.

In Chapter 4, the results for the research questions are presented. First, the summary of contribution of the studies for both the EDE method and UI design is shown. Next, the EDE method is presented as a main contribution to the first main research question. Then, the creation and the use of visual design examples and their benefits for AUX studies are explained. Next, the contribution to the second main research question is described and there is an explanation of how the interactivity of an object can be shown through its visual design. Then, the means of increasing the visibility of an object and the impact of the context on its visual design are presented.

In Chapter 5, the results and their connection to research questions of this thesis and related literature are reflected and discussed. The reliability and limitations of the studies are discussed as well. In addition, possible areas for future research are presented.

2 Conceptual background and related research

The content of this chapter is a combination of user experience and user interface design literature. First in sub-section 2.1, the background and the definition of user experience are described. Next in 2.2, the temporality of UX, expectations and anticipated user experience are explained. In the sub-section 2.3, designing for user experience is presented. Then in 2.4, the evaluation of UX, particularly early development phase challenges, is discussed. Finally in sub-section 2.5, related research on the studied user interfaces is introduced.

2.1 Defining user experience

User experience research builds on the roots of usability. The ideological shift from compulsory work-oriented use to leisure and personal use of computers as well as the availability of consumer products and services have led to an interest in expanding usability research to focus on UX. As Grudin (2006a) states, the business use of computers, which he calls as *non-discretionary* use, was in its peak in the 1960s when computers were so expensive that people had to keep them in continual use, which meant that users were almost seen as *slaves* when feeding information into them. Human factors research focused on efficiency and error reduction and training people on how to use these computers. In the mid-1970s, researchers started to anticipate that people would start to use computers free willingly. This became a reality when home computers, mini computers, personal computers (PCs), and workstations started to arrive in the 1980s. This demoralization of use began to change the research focus, as people's reactions to a new *discretionary* technology was not something that could be studied through controlled experiments and statistical data. (Grudin 2006a.) Although the change was coming, according to Kuutti (2002), users were still seen in the 1980s as a source of error. Usability testing was introduced in the late 1980s. It was based on users' observations when they were completing simulated tasks to identify potential problematic moments in the process (Kuutti 2009). Usability is described in ISO standard 9241-11:1998 (ISO 9241-210 2010) as:

“the extent to which a system, product, or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in specified use context.”

Although usability was the most dominant topic in HCI research from the 1990s until the early 2000s (Kuutti 2009), the first notions that usability studies were failing to provide data to design systems that people really want to use were written in the late 1980s, e.g., by Carroll and Thomas (1988). Still it took almost a decade before academia reacted to these writings (Hassenzahl & Tractinsky 2006), as in the mid-1990s there was a debate on the fact that HCI should go beyond the instrumental, task-orientation in evaluation and analysis (Alben 1996, Hassenzahl & Tractinsky 2006). Usability studies were seen as incapable of providing a complete understanding of system use (Alben 1996) and user needs (Jordan 1998). They were also perceived as being unable to provide knowledge on hedonic qualities: aesthetics (Alben 1996), pleasure (Jordan 1998), emotional needs (Desmet & Hekkert 2002, Norman 2004), enjoyment, and fun (Draper 1999, Monk *et al.* 2002, Blythe & Hassenzahl 2003) of the product, system, or service use¹. In addition, the usability of products and services was no longer seen as the selling point for consumer products (Kuutti 2009). Therefore, the terms experience and UX (Alben 1996, Pine & Gilmore 1998, Jordan 1998) were presented to be able to understand human-artifact interaction holistically. For example, Monk *et al.* (2002) called for re-focusing the research interests to the positive *motivators* instead of negative *stressors*. Jordan (2000) also criticized how the usability approach tended to see a person as a cognitive or physical processor, whereas pleasure-based approaches encourage a holistic view of users and a richer understanding of human diversity. Therefore, UX was perceived to take a real *human perspective* on technology use (Hassenzahl & Tractinsky 2006). Interest in UX expanded fast, and the term was widely used by the early 2000s (Forlizzi *et al.* 2008, Kuutti 2009, Bargas-Avila & Hornbæk 2011).

The actual meaning of user experience has been discussed in academia for as long as the term has been around and the discussion continues (Forlizzi & Battarbee 2004, Law *et al.* 2009, Roto *et al.* 2011). It did not help that practitioners fell in love with the term UX and replaced the term usability with it, which was quite understandable because UX covers a larger part of system use (Law *et al.* 2009, Bargas-Avila & Hornbaek 2011). As a consequence of the debate going on within academia, the standard definition (ISO 9241-210, 2010) of user experience was formulated in 2010 as:

¹ From this point on, the author will refer to products, systems, and services as products.

“a person's perceptions and responses resulting from the use and/or anticipated use of a product, system, or service.”

User experience is seen as an umbrella term for presenting new ways of studying and understanding the quality of use, and it has even been used to define the design, use, interaction, usability, or even user-centered design (UCD) (Bargas-Avila & Hornbaek 2011). Before and after the ISO standard definition, there were several varying views on UX. To understand these, the difference between experience and user experience first needs to be explained.

2.1.1 Experience

Human experience was studied in other disciplines before interest in it rose in the HCI area. It has been investigated and explained in the fields of design, philosophy, anthropology, cognitive science, and social science (Forlizzi & Battarbee 2004, Kuutti 2009). For example, in the field of psychology, Csikszentmihalyi (1991) studied flow experience and called it *an optimal experience*. Desmet and Hekkert (2007) state that in psychology, the term affect is used for explaining all kinds of subjective experiences of perceived pleasantness, unpleasantness, goodness, or badness. In business, Pine and Gilmore (1998) saw *experience economy* emerging and its expected changes to the design of services and business. Philosopher Dewey (1980) discussed *art as experience*, describing experience as occurring continuously without a person's awareness, but *an experience* requires *the material experience to run toward its fulfillment*. An experience can also be recalled after the fact from one's memory (Dewey 1980). Forlizzi and Battarbee (2004) defined three types of experience: *experience*, *an experience*, and a *co-experience*. Experience is happening all the time while being conscious and interacting with people, products, and the environment. An experience has a beginning and an end. It is a sequence of interactions that inspire behavioral and emotional change that is compressed into one experience that can be articulated or named. A co-experience is an experience created together or shared with others in a social context. (Forlizzi & Battarbee 2004.) According to McCarthy and Wright (2004), experience has four threads: sensual, emotional, compositional, and spatiotemporal. Fokkinga and Desmet (2013) divide all life experiences in two categories: ordinary and notable experiences. Ordinary experiences are quite neutral, but can have mildly positive or negative emotions involved. In the notable category, there are both pleasant/beneficial and unpleasant/unrewarding experiences. Rich experiences fall

under pleasant/beneficial experiences. (Fokkinga & Desmet 2013.) Lesage (2015) defined autotelic experience as an internal dimension of the Csikszentmihalyi's (1991) optimal experience, flow, and covering aesthetic experience and can occur during interactions. Researchers agree that experience is subjective and unique; thus, one person cannot have exactly the same experience as another (Dewey 1980, Pine & Gilmore 1998, Buchenau & Fulton Suri 2000, Forlizzi & Ford 2000, Battarbee 2004, Forlizzi & Battarbee 2004, McCarthy & Wright 2004, Hassenzahl & Tractinsky 2006, Desmet & Hekkert 2007, Arhippainen 2009, Law *et al.* 2009, Roto *et al.* 2011).

2.1.2 User experience

The term user experience emphasizes the use of an interactive product more than the term experience. Although many of the early studies about user experience define it as experience, the meaning can be understood as UX because it is about interaction with product. For example Alben (1996) define experience as dealing with all the aspects of how people use an interactive product, including the product's feel in users' hands, understanding how it works, its ability to serve its purpose, its fit to the entire use context, and how users feel while using it. Forlizzi and Ford (2000) define components that influence experiences: users, products, interactions, use contexts, and social and cultural factors. Users bring to the use situation all their emotions, prior experiences, and feelings. A product tells a story by its form, features, aesthetic qualities, and its accessibility. When a user is in interaction with a product, it occurs in a certain context that is influenced by social, cultural, and organizational behavioral patterns. (Forlizzi & Ford 2000.) Forlizzi and Ford (2000) note also that a singular experience contains an infinite amount of smaller experiences that are related to products, people, and contexts. According to Desmet and Hekkert (2007), experience is shaped by the characteristics of a product and user, which contain user actions, perceptual and cognitive processes, and influence the context. This interaction between user, system, and context, results into both hedonic and pragmatic layers of user experience (Hassenzahl 2004, Mahlke & Thüning 2007). Roto *et al.* (2011) define *experiencing* as an individual's subjective perceptions, interpretations of those, and consequential emotions that result from an encounter with a system. Hassenzahl (2008) defines UX as:

“a momentary, primarily evaluative feelings (good-bad) while interacting with a product or service.”

Desmet and Hekkert (2007) define product experience as:

“the entire set of affects that is elicited by the interaction between a user and a product, including the degree to which all our senses are gratified (aesthetic experience), the meanings we attach to the product (experience of meaning), and the feelings and emotions that are elicited (emotional experience).”

Roto (2006) limits the use of the user experience term only to situations in which a person is using, e.g., manipulating or controlling, a product. She suggests using the experience term in cases in which no system component is involved and experience arises from the context (Roto 2006). More recently, Roto *et al.* (2011) have extended the UX definition to deal with use, interaction, or passive confrontation with a product, service, or artifact, which one can interact with through a user interface. Law *et al.* (2009) limit the definition of UX only to interactions between a person and something with a UI. In 24 of the 27 definitions found on a webpage dedicated to UX (All about UX 2015) UX is defined as encompassing interactions with a product, system, or service. As Desmet and Hekkert (2007) note, UX is not a property of a product, but it is an outcome of the human-product interaction. UX is also seen as context-dependent (Forlizzi & Ford 2000, Battarbee 2004, Hassenzahl & Tractinsky 2006, Desmet & Hekkert 2007, Isomursu 2008, Arhippainen 2009, Jumisko-Pyykkö 2011). UX is described as also having a beginning and an end, e.g., it refers to individual or group experiences that people have felt over a certain period of system encounters (Forlizzi & Battarbee 2004, Roto *et al.* 2011).

2.2 Temporality of user experience

UX is also generally seen as a dynamic and temporal phenomenon, as it involves the ever-changing internal and emotional state of a person (Hassenzahl & Tractinsky 2006, Arhippainen 2009, Vermeeren *et al.* 2010, Law & van Schaik 2010, Luojuus 2010, Roto *et al.* 2011). Experience can also develop over time (Karapanos *et al.* 2009, Luojuus, 2010, Roto *et al.* 2011). Karapanos *et al.* (2009) note that temporality is becoming more important in research, as it is important to understand why a product becomes meaningful when incorporated into one’s daily life. According to Luojuus (2010), temporal or momentary experiences are linked in single actions that a user has experienced, while long-term experience is reflective and created cumulatively over time from UXs connected to certain activities guided by the user’s own motives. Luojuus (2010) claims that studying temporal UX alone

may not be reliable to use as the basis for design solutions. To gain a comprehensive understanding of user experiences, both temporary and long-term UXs need to be studied; thus, she suggests that UX studies need to be longer (Luojus 2010). Luojus is probably right, but in fast-paced projects, the evaluation period required for long-term studies makes it impossible to deliver UX-based data when designers and developers need it; thus, if long-term studies are done, they should be done in parallel with short-term studies.

The temporality of user experience has also created an interest in before-use evaluations of UX. This phase is probably the most important for the industry, as if users' future experiences with technology can be predicted in a reliable manner, it would provide quite valuable information for manufacturers. There are two issues that need to be understood to be able to study UX in before-use situations: user expectations and anticipated user experiences.

2.2.1 Expectations

User experiences are always influenced by a user's prior experiences and expectations that have been formulated based on his/her prior experience with products (Forlizzi & Ford 2000, Hiltunen *et al.* 2002, Kankainen 2003, McCarthy & Wright 2004, Wright *et al.* 2006, Arhippainen 2009, Roto *et al.* 2011, Olsson 2012). As Wright *et al.* (2006) explained, prior experiences with both everyday happenings and technology affect users' subjective experiences and expectations of a given situation. In addition, prior experiences that happened in a particular history and disposition significantly impact the personal meaning one ascribes to an experience (McCarthy & Wright 2004). Arhippainen (2009) noted that expectations start before use and they end long after use. They are also different before the use situation. In addition, users' most recent experiences are perceived to have a stronger impact on expectations and new experiences than those that happened earlier (Arhippainen 2009). According to Olsson (2012), other people and products from different product categories will affect users' expectations and experiences. A product's price will also have an impact on them, as Hiltunen *et al.* (2002) state that the more expensive a product is, the better the product it is expected to be. Expectations also direct users' attention when interacting with a product and after the interaction. They also affect emotional interpretations of the gathered knowledge. (Hiltunen *et al.* 2002.) According to Roto (2006), expectations that a user has before interacting with a product are a key aspect of the UX evaluation; in

particular, research should be done to determine whether these expectations are met when the product is used.

2.2.2 Anticipated user experience

Anticipated user experience is a new layer in the temporal investigation of UXs. Prior research has noted that people can have experiences before the actual use of a product or service (Roto *et al.* 2011, ISO 9241-210 2010). McCarthy and Wright (2004) view anticipation as occurring in two temporal phases: before and during an aesthetic experience. According to Roto *et al.* (2011), anticipated UX happens before the first use. In addition, it can happen also within the other time spans of UX, e.g., during and after the use and over time, as a person may imagine also during those time spans (Roto *et al.* 2011). A person can have indirect experience prior to the first use of a product or service through formed expectations of existing experience with related technologies, brands, advertisements, presentations, and other peoples' opinions (Roto *et al.* 2011). According to McCarthy and Wright (2004), anticipation is an endless process, suggesting something prior to the actual experience.

To define UXs that occur before the actual use, two terms have been used: *expectation* (Olsson 2012 & 2014) and *anticipation* (ISO 9241-210 2010, Yogasara *et al.* 2011). Is there a difference between these two terminologies? The Oxford Dictionary of English (Pollard & Liebeck 1994) defines the term *anticipate* as:

“to deal with use before the proper time; look forward to; expect,”

and in Merriam-Webster's online dictionary (2015), the term *anticipate* is defined as:

“to think of (something that will or might happen in the future); to expect or look ahead to (something) with pleasure; to look forward to (something).”

Oxford Dictionary of English (Pollard & Liebeck 1994) defines the term *expectation* as:

“a thing that is expected to happen; the probability that a thing will happen,”

and in Merriam-Webster's online dictionary (2015), the term *expectation* is defined as:

“a belief that something will happen or is likely to happen; a feeling or belief about how successful, good, etc., someone or something will be.”

Based on these dictionary definitions, the meaning of these two terms is quite similar. However, expectation places a stronger emphasis on the belief that something will or is likely to happen compared to anticipation, where the possibility is milder. Olsson (2012 & 2014) views anticipation and expectation as synonyms. However, expectation can also be seen in a larger context than that. For example, Arhippainen (2009) states that expectations are formed from all kinds of expectations that a person has toward to a UX experiment and the product under evaluation, not just toward the expected interaction or usefulness of the design. Based on this, the term anticipated might be a better and narrower concept to explain UXs in before-use situations.

Several preliminary definitions have been developed in an attempt to describe AUX. Yogasara *et al.* (2011) define AUX as the experiences and feelings that are expected to occur when a user is imagining using an interactive product. This definition and how they use it in their AUX research is problematic. Yogasara *et al.* (2011) asked subjects to imagine both a product and their interaction with it, which is quite a lot to ask from the subjects who are not trained to do that. According to Desmet and Hekkert (2007), non-physical interaction takes into account anticipated, remembered, and fantasized usage (Desmet & Hekkert 2007). They explained that one can also imagine, anticipate, or fantasize about the possible consequences of interaction. This definition is a bit more elaborate and also takes into account the consequences of the anticipated interaction. However, it also asks subject to imagine a lot without telling them how and by what means. Based on prior definitions described in this section, the author will use the AUX term to define *experiences, needs, and wishes that result from anticipated interaction with the concept of a product before the actual product exists.*

2.3 Designing for user experience

The shift from usability to UX has shifted the focus in product design and development away from implementing features and testing their usability toward designing enjoyable products that support central human values and needs (Väänänen-Vainio-Mattila *et al.* 2008). *Design for experiencing* should support emotional aspects of product use as well (Desmet & Hekkert 2007). In 1998, Pine and Gilmore predicted that experience design would become what product and process design were for business then. For current product development projects, a certain user experience is typically set as a target of the process, which makes the design more complicated (Forlizzi & Ford 2000, Forlizzi & Battarbee 2004). As

Sanders (2001) explained, experience design does not exist, as it is impossible to design something that lies in people. Redström (2006) also argued that *use, users,* and *their experiences* are not for designers to design. He clarified that the focus of the design should be an object, which is based on an understanding of the use seen as an achievement and the object that is experienced (Redström 2006). According to Hassenzahl and Tractinsky (2006), it is not clear whether it is possible to design an experience, as it is not easy to control all the elements affecting an experience. According to Desmet (2008), when the aim is to design for emotion, the subjective dimension makes it difficult to predict the resulting experience. Rather than attempting to design an experience, it is possible to design infrastructures that people can use to create their own experience, and this activity should be called *design for experiencing* (Sanders 2001). In addition, Hassenzahl and Tractinsky (2006) prefer to use the term *design for user experience* because even if all the experiential aspects are taken into account in the designing, there is no guarantee that a particular experience will be the outcome of the process.

Alben (1996) noted that each product requires its own unique process with user involvement, iteration, and multidisciplinary collaboration. Forlizzi & Battarbee (2004) categorize frameworks for experience-centered design created within the HCI area into three groups: *user-centered*, *product-centered*, and *interaction-centered*. User-centered frameworks help designers to understand the future users of the products. Product-centered models provide help for the designers in the process of creating products that can evoke compelling experiences. Interaction-centered models explore products' role in bridging the gap between users and designers. (Forlizzi & Battarbee 2004.)

Researchers have also developed methods for helping in designing for UX. For example, Lucero and Arrasvuori (2010) present *PLEX Cards* for designing playfulness. Lu and Roto (2014) suggest *experience goals* for expanding the design space and aiming to develop more radical design ideas. Arhippainen (2009) suggest *ten UX heuristics* for helping product and service design to take UX into account. According to Forlizzi and Ford (2000), beneficial products and experiences can be created through collecting subjective UXs and synthesizing them to construct a formalized narrative in the form of a product. The *user enactments* (UEs) method developed by Odom *et al.* (2012) allows a *fieldwork of the future* to be conducted to help designers to come up with more elaborate new technology concepts. In UE, subjects are asked to enact several future scenarios and reflect upon their own experiences to make sense of what they encountered. This approach helps to reduce risks and identify new opportunities, which would not be easy to accomplish when

studying current behaviors. (Odom *et al.* 2012.) Most of the earlier methods and tools have focused on positive experiences, but Fokkinga and Desmet (2013) suggest that a negative experience can make a product experience more rich and enjoyable. Fokkinga and Desmet (2013) introduce ten ways to design for negative emotions for not only pleasant contexts or phases in human life based on their *rich experience framework*.

2.3.1 Understanding the future user

Tools presented in previous section cannot solely help designers to achieve a certain user experience. To be able to design for experience, it requires from the designer a deep understanding of the people for whom they are designing (Forlizzi & Battarbee 2004). According to Väänänen-Vainio-Mattila *et al.* (2008), the design for UX is a user-centered development activity, as it is important to understand users' needs and values before designing and evaluating new solutions. Mattelmäki and Battarbee (2002) note that empathy is needed when the focus is on designing personal experiences rather than practical functions. Koskinen and Battarbee (2003) describe empathy as an imaginative projection of another person's situation, and trying to capture its motivational and emotional qualities. It requires understanding how the other person sees, feels, and experiences an object (can be also the environment or a service) in the situation in which it is used (Koskinen & Battarbee 2003). Moreover, according to Wright and McCarthy (2008), *knowing the user* involves understanding what it feels like to be in another's position. Wright *et al.* (2006) clarified that the idea is to understand other people's perspective, but not to lose one's own position at the same time. The traditional way of understanding users is through interviewing or observing them in real-life situations, but methods have been developed to understand a user when this is not possible. *Cultural probes* by Gaver *et al.* (1999) is a specially designed material package given to people to record their inspiration and information. The package contains a disposable camera, postcards with questions, an album, and a diary. The idea is to gather material in situations in which a researcher cannot be present (Gaver *et al.* 1999). Mattelmäki (2006) transformed the cultural probes method for design purposes and named it *Design probes*.

2.3.2 Human-centered design processes

Roto *et al.* 2011 claim that designing for UX is not very different from user-centered design. Human-centered design processes are meant for producing final products at the end of the activity. In the HCI area, several iterative human-centered design models have been developed. The most popular ones are the ISO standard model (ISO 9241-210 2010) and the Simple Lifecycle Model for Interaction Design (Rogers *et al.* 2011).

The ISO standard 13407 model (ISO 9241-210 2010) was initially developed to make interactive systems more usable. The process starts with carefully planning the design process. The actual model has four steps, indicating human-centered activities. First, the context of use needs to be understood and specified. It involves users and other stakeholders, their characteristics, users' goals and tasks, and the environment of the system. Second, users' requirements and needs for the system are to be specified, e.g., functional, organizational and other possible requirements for the product or system. Third, UI design solutions, user tasks, and interactions between the user and the system are designed and produced. Fourth, the user-centered evaluation is conducted, either in the form of user testing or expert evaluation. The method allows iteration wherever it is needed. And finally, when the user requirements are met, the design activities can be stopped. (ISO 9241-210 2010.)

The Simple Lifecycle Model for Interaction Design (Rogers *et al.* 2011) presents the activities that are related to interaction design. Like the previous ISO model, this design model has four basic activities: establishing requirements, designing alternatives, prototyping, and evaluating. The first activity is fundamental for user-centered design and is important for the interaction design. It is necessary to know the target users and what kind of support an interactive product could provide for them. Second, the ideas meeting the requirements are produced in addition to a conceptual model outlining what people can do with the system and the physical design of a product, including, for example color, sounds, images, menus, and icon design. Third, prototyping of the designed system is conducted. The prototyping techniques can vary from paper to software. Fourth, the user evaluation of the product is conducted. Then the results are fed back for further design. This process is also very iterative, allowing loose application, and steps can even be jumped over. Finally, in the end, a final product should be the outcome of the process. (Rogers *et al.* 2011.)

Smaller design processes exist as well, and one of them is the *UI design process* by Cox and Walker (1993). This process has three steps: exploration/incubation, generation, and evaluation. In the exploration step, the idea is to try to determine what the problem is and organize the different aspects of the problem to be able to look at the problem in many different ways. This can be done by drawing diagrams, listing things by writing them down, or trying to understand the qualitative problem in quantitative ways. This step can last from weeks to even years. Second, potential solutions are created. This is a creative activity and can be done by brainstorming innovative ideas in groups. Here it is important that the designer has good knowledge of the subject area to be able to create something novel. The third step is the testing of the ideas, which can be done with design sketches. Testing shows possible problems with the designs, but it also brings up ideas for new solutions. The process allows unsatisfactory solutions to be weeded out or reanalyzed and used in further work. Finally, the outcome of the process is one or more solutions to the problem. Different designers can end up with different solutions. (Cox & Walker 1993.)

In product and interaction design, the most experience-centered process is likely the *IDEOs five-step method* (Kelley 2001). This method requires understanding the design challenge, observation of users, and the use context first. In this step, the designer will be deeply involved in understanding and interpreting the use situation and user experiences in it. Second, the visualization of alternatives is done by sketching and modeling. Then the iterative prototyping, evaluation, and refinement are done until the process has reached the desired outcome. Finally, the outcome is a newly implemented concept for commercialization. (Kelley 2001.)

2.4 Evaluating user experiences

To be able to assess whether the created designs offer the intended UXs, they need to be evaluated with users. According to Vermeeren *et al.* (2010), the majority of basic UX study methods have been adapted from other disciplines. In particular, usability testing methods and social science methods are applied. Although methods are applied, as Kankainen (2003) suggested, user experience evaluation should not follow the traditional usability testing approach even if it is conducted in a laboratory setting. UX evaluations differ from usability evaluations drastically (Obrist *et al.* 2009). As Vermeeren *et al.* (2010) explained, UX is subjective, and evaluations focusing on understanding how a user feels about the system need other, more suitable methods than objective usability measures that are focused on the

task completion time and the numbers of clicks and errors. Monk *et al.* (2002) warned that HCI researchers focus too much on objective measurements and observing human behavior and are suspicious of users' introspective and personal judgments. Roto *et al.* (2011) also noted that evaluations can focus on one person's experiences from moment to moment while encountering the system. Lately a change has been seen, as Vermeeren *et al.* (2010) reported that approximately half of the pooled UX evaluation methods let subjects express their experiences in their own words. Jordan (2000) described a set of empirical methods and their suitability for evaluating design concepts, understanding people and the benefits that they want from products, and how to deliver benefits through the design. Interviewing was among these methods. Arhippainen (2009) and Goodman *et al.* (2012) see interviews as the best and most comprehensive way of collecting users' subjective experiences. According to Sanders (2001), it is essential to learn about people by listening what they say, watching their use, discovering what they know, and understanding what they feel. Still, semi-structured interviews have only been used in every fifth UX study (Bargas-Avila & Hornbæk 2011).

Over 50% of UX studies collected data through questionnaires (Bargas-Avila & Hornbæk 2012). The benefits of questionnaires are that they are fast, suitable for large populations, and easily quantifiable (Lazar *et al.* 2010). There are also different questionnaires developed specifically for UX evaluation purposes. The *AttrakDiff*TM semantic word pair questionnaire is meant for measuring interactive products' attractiveness (Hassenzahl *et al.* 2003). *Attract-Work* is a further developed version of it and is meant for mobile news journalism systems' evaluation (Väätäjä *et al.* 2009). Although most of the UX evaluations investigate short-term experiences during use, there is an interest in studying long-term UX as well. The qualitative *UX curve* developed by Kujala *et al.* (2011) is meant for investigating how and why UX changes over time. A survey tool called *iScale* by Karapanos *et al.* (2012) was developed for eliciting longitudinal UX data retrospectively. The *experience sampling method* (ESM) developed by Csikszentmihalyi and Larson (1987) combines interviews, surveys, and diaries. The aim of most of the short-term methods and questionnaires is the quantification of results (Vermeeren *et al.* 2010). When trying to understand this complex phenomenon only with quantitative methods, important subjective insights might not be identified, as they are not significant enough. Moreover, as Hart *et al.* (2013) pointed out, people's answers in quantitative surveys can be based on memory bound judgment of the complete experience, while interviews can arouse deeper reflection and thus reveal more refined and detailed information.

Although emotions and their evaluation are not the focus of this thesis, it is important to note that emotions are part of the HCI and UX research, and several methods exist for measuring them. The methods can be categorized into three groups: neuro-physiological, (bodily responses: brain activity, pulse rate, blood pressure, skin conductance, etc.), observer (facial expressions, speech, gestures), and self-report methods (diaries, interviews, questionnaires) (Lopatovska & Arapakis 2011). Neuro-physiological and observer methods are objective methods, but as Tscheligi *et al.* (2014) noted, they require both expensive equipment and skills to analyze and interpret the findings. Self-report methods have been developed to measure users' emotions during interactions. For example, *Self-Assessment Manikin* (SAM) by Bradley and Lang (1994), *Emocards* by Desmet *et al.* (2001), *Product Emotion Measurement* (PrEMO) by Desmet (2005), and an *Expressing Emotions and Experience* (3E-method) by Tähti and Arhippainen (2004) have been developed for the non-verbal self-reporting of subjective feelings by providing pictorial techniques. Tactile UX evaluation methods can also be used to measure emotions. The *Sensual Evaluation Instrument* (SEI) created by Isbister *et al.* (2006) allows UXs to be studied through physical objects that represent users' emotional states. Also other physical props are used to evaluate users' emotions with interactive systems (Tscheligi *et al.* 2014).

2.4.1 Early phase user experience studies

Early development phase UX evaluations are done to help select the best design for the development (Buxton 2007), evaluate whether the development is on the right track, or examine whether the final product meets the original UX targets (Stone *et al.* 2005). Väänänen-Vainio-Mattila and Wäljas (2009) reminds, that real empirical user data is needed especially in the early stages of the service development. Isomursu (2008) highlights the importance of evaluating before and after the product use in a setting that resembles an actual use setting. Olsson (2012) states that it is important to study users' subjective expectations, as they can offer inspiration both for the design and creation of evaluation measures. Although both prior research and the ISO standard (2010) mention anticipated use, most UX studies still focus on *during* and *after* the use, which is similar to traditional usability research (Bargas-Avila & Hornbæk 2012). Only 20% of the studies measured UX before the interaction and of those, 8% investigated user expectations (Bargas-Avila & Hornbæk 2011).

The challenge with early phase UX studies is that the artifact does not exist yet, which sets constraints for the studies. As Vermeeren *et al.* (2010) noted, participants need to use their imagination to be able to evaluate future interactive systems in the early design phase when no functional prototypes exist. Yogasara *et al.* (2011) AUX model requires subjects to imagine the product and interaction with it. This is problematic because as von Hippel (1986) stated, ordinary people are not able to generate new ideas that differ from their current products or systems, as their future needs are based on insights regarding their real-world experience. Goodman *et al.* (2012) also argued that people are much better at explaining their current activities than imagining future actions, and if they have to imagine them, they tend to oversimplify or idealize them. Olsson (2012) found that people's expectations were based on users' general needs, values, and experiences with other digital applications and services. As both von Hippel (1986) and Goodman *et al.* (2012) pointed out, users cannot see the future and they should not be put in a place where they have to imagine their future needs without giving concrete options for them. These concrete examples can give both researchers and participants a shared reference that allows participants to provide comments instead of struggling to imagine and communicate an example (Goodman *et al.* 2012). Therefore, in this thesis, all the AUX studies are conducted with visual stimuli.

2.4.2 Early development phase AUX evaluation methods for investigating the visual design of an artifact

There is a recognized need for user experience evaluation methods for early phase studies. According to Vermeeren *et al.* (2010), only 25% of UX evaluation methods are suitable for concept phase studies, even less (23%) for the non-functional prototype phase, and only 7 of them are applicable online. If the study is focused on UXs with aesthetics and/or the appeal of a product, the amount of early phase methods drops to 15% (Bargas-Avila & Hornbæk 2012). Furthermore, according to Väänänen-Vainio-Mattila *et al.* (2008), there are fewer methods that can evaluate the experiential aspects of a concept.

AUXs are often studied merely by interviewing users with or without written scenario. According to Diederiks and Hoonhout (2007), when studying incomplete or radical innovation ideas with users, it is better to use scenarios that contain both textual descriptions and images of the concept idea because in that way, ideas are more tangible for the users and thus can generate more concrete feedback on the proposed solution. Buxton (2007) suggested using a design research method called

co-constructing stories (CCS) when evaluating concepts in the early design phase. The main idea is to question whether the concept is going to lead to correct design that is able to bring added value for its users, why people believe the concept will provide added value for them, and how it should be developed further to be able to provide added value in use (Buxton 2007). The *speed dating* method developed by Davidoff *et al.* (2007) does not require subjects to imagine the future, as it allows them to rapidly explore different application concepts to depict their current needs in the context of imagined future technology. It is also possible to enable participants to imagine and evaluate a possible future product with a product, interactive prototype, paper, and/or a virtual prototype (Arhipainen 2009, Vermeeren *et al.* 2010), storyboards (van der Lelie 2006), sketches, mock-ups, and videos (Kolli 1993). According to Walsh *et al.* (2014), these methods require both design knowledge and cultural understanding to be able to support and motivate subjects to participate and prevent interpretation errors by adjusting the study material to suit the cultural context. *Photo elicitation* can also stimulate vivid, concrete, and meaningful words by collecting and assembling pictures by the researcher or the subject (Goodman *et al.* 2012).

There are only a few other methods currently available for early phase UX studies. Vermeeren *et al.* (2010) found that out of 96 UX evaluation methods, only one asks subjects to imagine the concept in different situations, e.g., anticipating a future with it; the method is called *Immersion* (Jordan, 2000). From the webpage dedicated to UX (All about UX 2015), only three out of 82 methods can be found that enable anticipated experiences to be studied with visual examples: *AXE* by Gegner and Runonen (2012), *KESo* by Shütte (2006), and *paired comparison* by Lavrakas, (2008), which deal with visual aspects of a product and some visual stimuli used in early phase user studies. *AXE* is a qualitative method that utilizes concept narratives read aloud, which are evaluated with image pairs in the form of semantic differential pairs without 5- or 7-point scales (Gegner & Runonen 2012). The problem is that the user needs to understand both the concept narrative and the shown ambiguous image pairs correctly to be able to evaluate the concept. Otherwise, the results will not be trustworthy. The non-ordinal scale also does not make the analysis of the results easy. *KESo* and the paired comparison are quantitative methods. In the paired comparison, two things are being simultaneously compared with each other by a subject and a binary scale is used to indicate which of the two choices are, for example, most preferred, most pleasant, or most attractive (Lavrakas 2008). The *Kansei Engineering* (KE) method was originally developed by Nagamachi (1995), and the idea is to translate the image

of a product into design elements and user feelings into the product parameters. The KESo method is based on the original KE method by making it more efficient and easier to follow in the evaluation, but it still requires a lot of time and expert knowledge in the areas of engineering, statistics, and psychology (all about UX 2015).

2.4.3 Prototypes in early development phase AUX studies

Early development phase AUX studies are challenging, as the design is in the concept phase; thus, nothing completely ready exists yet. To be able to study how users perceive a suggested design concept, some sort of a prototype or visual representation is needed. According to Buchenau and Fulton Suri (2000), prototypes are representations of a design before the final designed artifact exists, and they can range from sketches to models: *looks like*, *behaves like*, and *works like*.

Roto (2006) believes it is beneficial to evaluate immature technology, as by doing so researchers can understand the characteristics of the UX and are then able to design more delightful products for users. However, in early phase studies, functional prototypes hardly ever exist, as studies might be done before the implementation has begun and implementations can take longer than assumed. In addition, if the functional prototype is implemented as a *proof-of-concept* from a technological development point of view, e.g., showing that it can be implemented and it is working (Wiberg & Stolterman 2014), the visual quality is hardly ever suitable for studying the visual UI design and aesthetic experience. This is problematic because both usability and visual design limitations will impact the UX. As Desmet and Hekkert (2008) noted, usable products are more likely to elicit positive emotions than less usable products. Tractinsky and Hassenzahl (2005) stated that one negative interaction can have a negative impact on a person's well-being, and negative experiences in interactions tend to have more weight in retrospective assessments even if the majority of experiences have been positive. Arhipainen (2009) also stated that a novice user might have different presumptions of the evaluation and thus, can expect that it will be difficult to interact with the functional prototype. This might lead to nervousness and possible errors when interacting with the functional prototype (Arhipainen 2009). Visual aesthetics plays an important role in users' experience of a product as well (Tractinsky 2013). Thus, when visual UI design and aesthetics are studied, the researcher has to acknowledge that people are used to seeing high-quality graphics

on their personal devices. Therefore, their prior experiences will impact how they evaluate the functional prototype, its visual user interface design, and aesthetics. This sets higher requirements for the visual design of the functional prototype.

There are different types of prototypes with varying levels of interaction that can be used in early phase user studies. An *experience prototype* can be any kind of representation, in any medium, that is designed to be understood, explored, or to communicate engagement with the designed artifact. It can be used to understand existing UXs, context, or exploring and evaluating design ideas. (Buchenau & Fulton Suri 2000.) When artifacts are used in early phase UX studies, they should be carefully created. As Roto *et al.* (2011) noted, it is difficult to give people a sense of the experience before the actual design is available. Thus, to be able to make accurate predictions of UX based on AUXs, Law (2011) pointed out that the early design artifacts need to be flexible enough to enable altered feedback to be gathered from the subjects, but they should also be inflexible enough to enable their key characteristics to be transferred to the final design. According to Sanders (2001), the methods should also be capable of evoking peoples' dreams to illustrate how their future could be changed for the better.

Concept design phase UX evaluations are difficult because the concepts are typically quite abstract and their presentation technique inevitably determines how valuable the feedback can be that is gained from evaluation participants (Gegner and Runonen 2012). According to Roto *et al.* (2009), the danger in concept phase evaluations is that an excellent concept idea can suffer as a result of a boring or poorly done presentation, and therefore subjects might prefer a less promising concept if it is presented as more appealing. Thus, preparing easy to understand concept descriptions for the studies' subjects that are at the same level visually can be laborious (Roto *et al.* 2009).

The role of the designer is important when creating visual examples for the early phase user studies that focus on aesthetics (Alben 1996). It is critical that participants are able to understand a new idea or a vision through the designer's presentation (Löwgren & Stolterman 2007, Buchenau & Fulton Suri 2000). The presentation technique should allow the designer to make ideas *visible* for the evaluation participants so that they are able to *see*, analyze, and evaluate them (Löwgren & Stolterman 2007). In early phase UX evaluations, it is even more important that the design team is able to create representations of the system that stimulate users to give feedback on design directions, capture emotional responses, and give explanations for both (Roto *et al.* 2011). In addition, van den Hende (2010) asserted that the presentation method of the designed concept should be able to

stimulate the participant's imagination to be able to envision the future value of the concept. The presentation of a concept can vary from sketches to textual and verbal presentation of the concept (Roto *et al.* 2009). According to Ozcelik Buskermolen *et al.* (2015), the sketchy presentation of a concept enables more detailed feedback and improvement suggestions to be elicited based on prior experiences, whereas visually refined images are more helpful when trying to elicit definite judgments from participants. Kankainen (2003) suggested that low-fidelity prototypes should be presented with scenarios, and subjects should be asked to describe where they would use the product concept in their everyday lives. Gegner and Runonen (2012) suggested that early prototypes and simple visual representations of a concept should be used to give participants a concrete example they can refer to during the evaluation. In the concept design phase, there are usually several alternative design concepts under design, as Kankainen (2003) suggested it is more feasible to build low-fidelity prototypes of them than implementing them as functional prototypes. Virtual models can also be used in evaluations. But as Kuutti *et al.* (2001) explained, if the virtual model is to represent a real product, then the model's quality should be sufficiently high to be able to prevent additional confusion. In early phase studies, participants need to be able to focus on studied features in the prototypes to be able to gain reliable results from the user evaluation. According to Lim and Stolterman (2008), if the design space is large, it is not feasible to explore it as a whole, but a designer should filter interesting qualities that can be studied through the prototype.

2.5 Visual user interface design

Visual user interface design today is commonly called UX design. It deals with the graphical and interaction design of the UIs. A user interface is defined in the ISO 9241-110 2006 standard (ISO9241-210 2010) as:

“all components of an interactive system (software or hardware) that provide information and controls for the user to accomplish specific tasks with the interactive system.”

There are different kinds of UIs, but this thesis will focus only on those that were studied in the design cases: virtual and physical user interfaces. Virtual user interface exist only as bits and is interacted through input device. In a physical UI the interaction is done through a physical object and/or environment. The virtual user interfaces on two-dimensional (2D) screens that were investigated are: graphical UIs in touchscreen mobile devices and 3D UIs in the form of virtual

environments (VEs) interacted through 2D input devices or a touchscreen. The studied physical user interface combined wearable, tangible, and deformable UIs.

According to prior research, aesthetic aspects of digital artifacts have not been extensively dealt with in HCI (Tractinsky 2004, Löwgren & Stolterman 2007). Aesthetics has been seen as rather superficial compared to usability and is thought to be related solely to the color or shape of an object (Löwgren & Stolterman 2007). According to Tractinsky (2004), visual appeal and aesthetics are integral parts of the interactive system design. Alben (1996) noted that aesthetically pleasing and sensually satisfying user experiences with a product are based on the product's coherency and continuity in its design in all design fields: graphics, interaction, information, and industrial design. According to Tractinsky (2013) aesthetics has a large impact on UX because it is an antecedent of emotions and enjoyment. According to Postrel (2002), computer-driven demoralization of design has made people aware and sensitive to graphics and aesthetic quality. Ultimately, this awareness will lead to a greater need for aesthetics (Maslow 1954, Postrel 2002, Tractinsky 2004). Norman (2004) claimed that the aesthetic design of objects can have a larger influence on user preferences than the usability of the product. Findings of De Angeli *et al.* (2006) confirm this, as a more attractive UI was preferred even though it was less usable than the less attractive version of it. Arhippainen (2009) also explained that visual design can both make the UI aesthetically pleasurable and improve the usability of the UI by making it more understandable, consistent, and guiding. Thus, the visual design of a UI is a critical factor for its success.

2.5.1 2D graphical user interface

Most of the current user interfaces that ordinary users are using are graphical direct-manipulated ones. The graphical user interface (GUI) was invented in the 1970s by researchers in Xerox Palo Alto Research Center (Xerox PARK) (Press 1990). Xerox Star computer was announced in 1981 (Smith *et al.* 2001) and utilized Windows, Icons, Menus, and Pointers (WIMP) (Press 1990). The computer did not become commercially successful, but the UI paradigm was utilized in 1983 launched Lisa computer developed by Apple (Cambell 2001). It also did not become commercially successful, but it opened the door for the popularization of GUIs in PCs. The Macintosh computer from 1984 then became the first commercially successful computer with a GUI. (Press 1990.) The final breakthrough of GUIs occurred in the early 1990s, when Microsoft made the

decision to use only GUIs in their Windows operating system version 3 (Grudin 2006b). The next big turn in GUIs' history occurred in the early 2000s, as they were used in mobile phones. In 2007, icons played a significant role in GUI interaction in smart phones as the first touchscreen smart phone was introduced by Apple (2015). In 2010, a GUI was introduced into mobile tablet devices by Apple (2015).

As the name implies, a GUI presents the content in a graphical form; thus, the visual and graphical design of its elements are central in its development. Most of the user interaction happens through graphical icons in the GUI. Icons can present their content either in pictographic form, e.g., pictorially presenting the relationship to a physical object or action, or in ideographic form, e.g., representing the concept visually (Cambell 2001, Harrison *et al.* 2011). But as Harrison *et al.* (2011) state, icons or other visual elements' properties can be modified to give users extra information, such as presenting forbidden actions by dimming a button or presenting the progress of a task with an animated progress bar. Prior research has demonstrated icons' universal comprehensibility (Garcia *et al.* 1994, Pappachan & Ziefle 2007, Schröder & Ziefle 2008b) and their superiority with respect to usability (Whiteside *et al.* 1985, Egido & Patterson 1988).

2.5.2 Touch screen mobile user interfaces

A mobile device is a device that is meant for information processing and communication in on-the-go situations. These devices have a network connection and global positioning system (GPS) that allows users to rely on a variety of applications for navigation or connecting to peers. Mobile devices include all the small portable devices, ranging from USB storage devices, portable digital assistants (PDAs), laptop computers, tablet computers, mobile phones, and smartphones. Radio and mobile frequency identification devices (RFID) and infrared-enabled devices (IrDA) are also included in the category. (Johnson & Maltz 1996.) The difference between smart phones and tablets is the size. Current smart phone screen sizes vary between four to seven inches and tablet device screen sizes start at six and go to even 24 inches.

The prior research on mobile UIs has been lively, and there are several communities investigating this area, both from interaction and visual design points of view. The role of icons in user interaction has grown because of touchscreen smartphones. Thus, they have interested the mobile HCI community. According to Schröder and Ziefle (2008a), the benefit of icons in mobile devices is their intercultural understandable language. Prior research has investigated icon design,

the suitable size of the icons (Chen *et al.* 2009), and the amount of icons shown in parallel on the screen (Geven *et al.* 2006). How people organize icons in a GUI has also interested prior researchers (Böhmer & Krüger 2013). Still, researchers have not focused a great deal on the visual design of the icons.

2.5.3 3D user interface

One sub-area of graphical user interface is 3D UIs. Bowman *et al.* (2005) define a 3D UI as a UI that includes 3D interaction. By 3D interaction, Bowman *et al.* (2005) mean:

“Human–computer interaction in which the user’s tasks are performed directly in a 3D spatial context. Interactive systems that display 3D graphics do not necessarily involve 3D interaction; for example, if a user tours a model of a building on her desktop computer by choosing viewpoints from a traditional menu, no 3D interaction has taken place. On the other hand, 3D interaction does not necessarily mean that 3D input devices are used; for example, in the same application, if the user clicks on a target object to navigate to that object, then the 2D mouse input has been directly translated into a 3D location, and thus 3D interaction has occurred.”

In other words, the 3D virtual environment (VE) that is displayed on a 2D computer screen and interacted via a mouse, keyboard, or touchscreen is a 3D user interface if the interaction happens through objects in 3D VE and that interaction can be translated into a 3D location. The research of 3D UIs and VEs started in the late 1960s and has been quite extensive. The early research was heavily technology-driven (Bowman *et al.* 2006). The greatest research effort has been placed on investigating 3D interaction techniques for *universal 3D tasks* of selection, manipulation, traveling in VEs, and system control, which all are fundamental building blocks of the 3D UIs (Bowman & Wingrave 2001, Bowman *et al.* 2006). As a 3D UI is also a depth dimension, it allows a larger set of items to be displayed simultaneously in the UI space. Therefore, researchers have investigated 3D file browsing and displaying of hierarchical information (Robertson *et al.* 1991, Cockburn & McKenzie 2001, Leal *et al.* 2009). Different kinds of 3D menus (Bowman & Wingrave 2001, Liang & Green 1994) and metaphors have been extensively investigated over the years (Dachselt & Hübner 2007, Gotchev *et al.* 2011). The most frequently used 3D metaphors for mobile 3D media are tree, mirror, elevator, book, art gallery, card, and hinged metaphors (Gotchev *et al.* 2011). Lately,

some 3D metaphors have also been utilized in touchscreen 2D UIs, such as a bookshelf metaphor (Card *et al.* 1996), which was quite popular for displaying content, for example, in the first version of iPad (Apple 2015). 3D carousel metaphors have also gained considerable attention, both in industry and academia (Liang & Green 1994, Wang *et al.* 2005, Patterson 2007, Jacucci *et al.* 2010). Different kinds of 2½D (Agarawala & Balakrishnan 2006) and 3D desktops have been designed and studied as well (Staples 1993, Light & Miller 2002).

3D UI makes it possible to interact with VEs, objects, or information in the 3D space (Bowman *et al.* 2008). VEs are synthetic 3D spaces that are rendered in real time under the direct control of users (Bowman 2005). The technologies and technological integration for VEs were realized in the late 1960s by Ivan Sutherland (1968). Perhaps the most popular VEs among typical users are the collaborative virtual environments (CVEs) or virtual worlds (VWs), such as Second Life (2015) and World of Warcraft (2015), where users are presented as avatars in a 3D space. These CVEs have attracted researchers from education (e.g., Dickey 2004, Minocha & Hardy 2011) and in the tourism sector (e.g., Sweeney & Adams 2009, Huang *et al.* 2010 & 2013). It is even claimed that virtual worlds, such as Second Life, could become an optimal marketing platform for the tourism sector (Huang *et al.* 2010). There is currently interest in using virtual reality (VR) technology in destination marketing because VEs are perceived to simulate real visits and the gained virtual experience is quite similar to the real-life experiences (Buhalis & Law 2008). According to Hobson and Williams (1995), the use of virtual reality systems can also help users to make better-informed decisions and have more realistic expectations, which leads to a more satisfactory vacation in real life.

Although research has been done for over three decades, 3D UIs and virtual reality (VR) is in its infancy. This is because the hardware is immature and requires a lot of maintenance to keep it running. Another major problem is that VR systems cannot be used productively without extensive training. Instead, many 3D games and online virtual worlds with 2D input devices are easy to access and their interaction affordance is fast adaptable. (Bowman *et al.* 2008.) Initially, many of the interfaces to VR applications were designed to be *natural*, which means that to be able, for example, to view a virtual space, users have to walk or fly around it, which makes interaction inefficient, frustrating, and impractical (Bowman *et al.* 2006). To design more accessible 3D UIs, Bowman *et al.* (2008) offer guidelines. Objects should not float in 3D UIs, as in the real world, objects are always attached to some other objects. Second, solid objects should not interpenetrate to prevent users from getting trapped anywhere in the VE. Third, interaction should be only

possible with visible objects, e.g., not objects that are occluded by any other object. Fourth, perspective and object occlusion are the strongest cues for presenting objects' position in UI depth.

Commercial 3D interaction-enabling devices, such as Nintendo Wii (Nintendo 2015), Sony PlayStation (Sony 2015a), and Microsoft Xbox (Microsoft 2015), made 3D UIs available for all. These products are easy to use, as their interaction resembles real-life human interactions; for example, when bowling or playing tennis, the spatial interaction with the Nintendo Wii controller mimics the actual interaction in the real world (Bowman *et al.* 2006). According to Bowman *et al.* (2006), the design space for new investigations of 3D interaction metaphors is limited because of the huge amount of research conducted in the mid-1990s. However, after that, new multi-touch enabling screen-based mobile devices appeared on the market, which have opened the area back up for investigation. Mobile devices, smart phones, and tablets have more and more computing power to run 3D meshes and they have built-in sensors, and high-resolution, multi-touch screens, which allow them to be used in 3D UI tasks (Wang & Lindeman 2014). This has led to new research on ways to apply 3D UIs in emerging technological areas (Bowman *et al.* 2006). Research on 3D UIs and interaction on touchscreen mobile devices has investigated, for example, 3D VEs on touchscreen tablet-sized devices with object-based interaction (Hickey *et al.* 2012), hybrid UIs where the tablet is a supplementary tool (Wilkes *et al.* 2012), or as a part of the whole UI (Wang & Lindeman 2014). Touchscreen technology has extended the research to new device areas as well, such as on larger touch displays on tables (Ståhl *et al.* 2002, Hancock *et al.* 2009) and on the wall (Jacucci *et al.* 2010).

The problem with prior 3D UI research is that there has been a heavy emphasis on the technical development and usability of the systems. Users' subjective feelings and needs for the technology have not been areas of focus in 3D UI research. However, there has clearly been an increasing interest in studying UX since the beginning of this decade. For example, Jumisko-Pyykkö (2011) studied the quality of experience of the 3D mobile television in a comprehensive way, both qualitatively and quantitatively. 3D game researchers are interested in UXs, maybe because games are naturally a fun application area, while researchers of 3D interaction are still more eager to measure UX with questionnaires and psychophysical instruments (e.g., in Schild 2012) than taking a qualitative approach to understand users' needs and wishes holistically. Only in the very latest research have interview techniques been used for collecting subjective comments about the benefits and drawbacks of the developed prototypes (Wang & Lindeman

2014). This shows that this very technically oriented research field is beginning to extend beyond measuring task completion times and user performance. Still, aesthetics aspects of 3D UI design have not been the focus of prior research.

2.5.4 Visual attention in 3D user interfaces

Visual attention processes have been studied extensively within cognitive science, neurology, and psychology, but also within VEs, especially task-oriented VEs, such as interactive 3D games (Beeharee *et al.* 2003, Bernhard *et al.* 2010, El-Nasr & Rao 2004, El-Nasr & Yan 2006). Treue (2001) and Beeharee *et al.* (2003) defined human vision as a complex and active process involving interpretations based on prior experience, habits, and expectations and a selection process that *draws* our eyes to explore a particular area of the scene. Perception is not a trivial task; it is the end of an unaware complex process (Goldstein 2002). The purpose of the early sensorial processing of information is to extract relevant characters from the perceived information (Jumisko-Pyykkö 2011). Visual perception theory assumes that it is impossible to store a detailed and complete image of a scene to visual memory (Rensink 2000). To be able to have a perception that the scene is complete, a user needs to create a *just-in-time* representation of it (Hayhoe *et al.* 2003). According to Beeharee *et al.* (2003), this means that a user is constructing a representation of the scene based on his/her experience of reality, understanding of the scene, and some parts of the scene in more detail. In this way, a user perceives the scene as complete and detailed, but is actually *blind* to the missing detail (Beeharee *et al.* 2003).

Visual scenes contain a huge amount of information that cannot be identified or recalled with a single fixation (Beeharee *et al.* 2003). This is a problem, especially for novice users. As El-Nasr and Yan (2006) explained, novice users get lost more easily in 3D game environments or they do not notice an important item. Minocha and Hardy (2011) also noted that navigation and finding a way to a wanted location can be difficult in collaborative VEs because the lack of directional signs or badly designed ones. Shneiderman (2003) argued ten years ago about making 3D UIs to facilitate user tasks with an enhanced 3D design rather than just mimicking reality in all possible ways. To design visually enhanced 3D UIs and games, El-Nasr and Yan (2006) highlighted the importance for visual indication, especially for novice users. Visual indication is widely used in 3D games in which fast performance is critical in different situations, such as finding equipment, energy, or routes. For example, in *Serious Sam 3 BFE* (2015) the energy blood

bottles are indicated with an animated color change from red to white-turquoise; the indication is shown on the bottle as a color overlay or as a colored edge, depending on the viewing distance. The situation is entirely different within 3D VEs, such as Second Life (2015).

Psychologists agree on color being a pre-attentive feature (Green & Andersson 1956, Smith 1962, Carter 1982, Bundesen & Pedersen 1983). The suggested ways for indicating objects in 3D VEs differ. Pichler (1993) studied four strategies for an anchor highlighting in a 3D scene. The strategies were bounding cube, brightness, color code, and color edges, of which the color code was found to be the best in usability tests. It was also the users' favorite choice for the highlighting mode, whereas a color edge was the most visually appealing choice (Pichler 1993). Beeharee *et al.* (2003) suggested a visual attention model for densely populated, behaviorally rich, and highly interactive distributed VEs: *bottom-up* components (e.g., visual aspects of the environment) and *top-down* components (e.g., semantics of the environment, such as relationships and behavior properties of the objects, the role of the participant, the task, and the activity). According to Jumisko-Pyykkö (2011), top-down processing combines humans' prior knowledge in the form of expectations, attitudes, emotions, and goal-oriented action toward perceptions. Color and orientation have been found to be significant to visual attention, and here, specifically, objects with highly contrasting colors or orientation compared to their neighbors are most likely to gain visual attention (Beeharee *et al.* 2003). In some cases, people are not able to notice an obvious change, which is called change blindness (Archambault *et al.* 1999). The number of objects that can be highlighted simultaneously is also limited. According to Pylyshyn's (1989) *FINST Indexing Theory*, only four to six perceptually significant objects or features can be *indexed* to be used in later cognitive processes as references. In addition, user behavior can impact how information should be presented. As Cotte *et al.* (2006) point out, consumers with utilitarian behavior are more task focused and therefore more interested in information searches than the experience itself. On the other hand, pleasure-orientated consumers typically enjoy using, for example, the Internet to play games or chat (Buhalis & Law 2008).

The problem with prior research on visual indications of interactive content is that some of the findings are quite old, and thus their suggestions may not be applicable anymore. Technological development has improved both the screen quality and processing capabilities of devices within the past five years, and now more detailed 3D graphics can be shown and run, even on mobile devices.

2.5.5 Tangible user interfaces

Tangible UIs build on Mark Weiser's (1991) ubiquitous computing vision in which computers are made invisible. Ishii and Ullmer (1997) defined this to mean tangible user interfaces (TUIs) and they stated that:

"TUIs will augment the real physical world by coupling digital information to every physical object and environment."

In this UI category, this thesis examines a more limited version of TUIs, as only one wearable, tangible, and deformable UI is in focus.

Wrist-worn wearable UIs

Smartphones offer a large variety of applications, and their size is growing; thus, they are no longer as easy to put into the pocket of a user's sweatpants while playing sports. At the same time, technology is becoming more petite and offer new possibilities for wearable devices. Wrist-worn devices in particular are of interest in both academia and industry, as the wrist is considered the best location for optimizing interaction in terms of reaction times and consistency (Harrison *et al.* 2009).

In commercial products, the hype for wrist-worn devices is high at the moment. The most common and traditional wrist-worn sports-related computing devices are heart rate monitors (e.g., Polar 2015) and dive watches (e.g., Suunto 2015). Another more recent device category is the small screen or screenless accessory device for fitness or health monitoring. Nike+ SportWatch (Nike 2015) is an example of a fitness tracking device that can record jogging-related measures such as pace, distance, and calories. Fitbit Flex (2015) is meant for the health monitoring of activity and sleep. The Razer Nabu (2015) is intended for both fitness and personal communication. It has two screens located on the opposite sides of the bracelet; the outer is meant for public content, whereas the inner is for private content, such as emails. In addition, smartphone manufacturers have entered the wrist device markets with smart watches. Samsung was the first mobile phone manufacturer, who brought the Gear watch to the market (Samsung 2015). Sony has released a SmartWear product family including the SmartWatch and two types of SmartBands (Sony 2015b). Android (2015) and LG (2015) have also brought their smart watches to the market. All the previously mentioned smart phones utilize the Android Wear operating system (OS) (Android 2015). Apple was the last

manufacturer to bring its Apple Watch (Apple 2015) to the market. Its operating system is Watch OS. These devices are marketed as the most personal devices ever (Apple 2015), which is partially true, as they are close to one's skin and always on. The watches are synced with smart phones, but they contain fewer applications than the phones. Applications for the watches are for example meant for communication, navigation, and fitness and health monitoring (Apple 2015).

Academic researchers are also interested in small wearable UIs. IBM released the first functional watch computer called Linux Watch in 2001 (Narayanaswami *et al.* 2002). According to Perrault *et al.* (2013), the problem with wrist-worn devices is that the space for interaction is very limited; thus, it is difficult to select small objects via buttons or on-screen. Researchers have tried different kinds of interactions to solve the problem. Yatani *et al.* (2008) suggested visually-cued gestures for object selection. Baudisch and Chu (2009) offered back-of-the device interaction as a solution. Perrault *et al.* (2013) investigated a prototype that allows interaction with the wristband of the watch-type device. Lyons *et al.* (2012) suggested a *Facet* prototype as a solution, as it has six small screens in the form of a bracelet for input and output for different applications. Holleis *et al.* (2008) offers guidelines for wearable controls that are, for example, the need for one-handed interaction, immediate feedback, and easy and fast location of controls.

As technology keeps evolving toward smaller hardware and components, the aesthetics and visual design of the wearables has also begun to interest researchers. Ashbrook *et al.* (2011) investigated interaction input with an interactive ring called *Nenya*, where interaction works by turning the ring. According to McCarthy *et al.* (2006), users would be more willing to wear and use a device if its aesthetics can charm them to do so. Miner *et al.* (2001) believe that if the device is perceived not to be interfering and inadequate, it is easier to fully integrate it into everyday life. Wallace *et al.* (2007) also noted that the aesthetics, comfort, behavior, and functionality of a worn device are crucial for its acceptance. Fortman *et al.* (2013) noted that people identify themselves with the things they wear on their body. Thus, aesthetics and the exterior design of a device are important to investigate in research. The concept ideas of the aesthetical jewelry type of wearables have been presented in prior research. For example, Ahde and Mikkonen (2008) developed a hello communication bracelet that tells users if a friend is nearby by showing color signals on the bracelet. Fortman *et al.* (2013) created a charm bracelet that works as a daily reminder, showing information by both the shape of the charm and its color.

The problem with prior research on wrist-worn UIs is that they have either merely focused on the interaction with GUI-based UIs or presented some novel aesthetically pleasing solution in the very early concept phase. These concepts have neither been evaluated by possible future users nor implemented yet as a functional prototype. Thus, new research on wearable tangible UIs is needed to find new form factors for wrist-worn devices and users' needs and wishes regarding the aesthetics aspect and behavior of these UIs. Moreover, no research has been done on the visual design of interactive objects in these UIs.

Deformable, flexible, and shape-changing user interfaces

There has been interest in studying flexible, deformable, and shape-changing handheld UIs and interaction for over a decade. Rasmussen *et al.* (2012) explained that in a shape-changing interface the input and output are created by a physical shape change. Most of the early work has been explorative concepts, as the large and rigid form factors of technology have limited the creation of deformable and shape-changing UIs (Vertegaal & Poupyrev 2008). For example, Schwesig *et al.* (2004) investigated interaction concepts with their flexible handheld device called Gummi. The recent development of the technology has led to the combination of two emerging technology trends, wearable computing, and physical deformable, tactile interfaces in the research. In addition, deformable materials, such as soft composite materials (Yao *et al.* 2013), and the availability of smaller hardware, such as Arduino (2015) boards, have led to experiments in which the aim is to create small deformable UIs. Several recent studies have investigated user interaction with deformable (Ramakers *et al.* 2013, Steimle *et al.* 2013) or foldable displays (Lee *et al.* 2008, Khalilbeigi *et al.* 2012). Kildal and Wilson (2012) investigated the stiffness and deformation range of a bendable handheld device and found that soft materials were perceived as more desirable and able to offer a more comfortable and engaging interface. These flexible materials have also inspired novel communication device concepts, such as MorePhone by Gomes *et al.* (2013) and the Kinetic device mobile interface concept by Kildal *et al.* (2012). Technology development also allows more future possibilities for deformable interfaces. One of the most promising technologies for deformable UIs is the PneuUI developed by Yao *et al.* (2013). It allows shape-changing interfaces to be created through pneumatically-triggered soft composite materials that integrate both input and output capabilities (Yao *et al.* 2013).

Although most prior research on deformable UIs is innovative, the focus is, as Rasmussen *et al.* (2012) pointed out, on technical development. They suggested that future research should collect high-quality data on overall user reactions toward these interfaces, how these UIs could be used, and in what contexts (Rasmussen *et al.* 2012). Thus, more UX-based research is needed to be able to understand users' requirements, needs, and wishes for this technology.

3 Empirical research methods and materials

In this section, the empirical research materials and methods are described. The research approach is presented in sub-section 3.1. Next, in 3.2, the focus and development phases of the studies are explained. In sub-section 3.3, the studied artifacts are presented. In 3.4, the study settings are described. In sub-section 3.5, the data collection methods are explained. In 3.6, the characteristics of study participants are described. Finally, in sub-section 3.7, the data analysis methods of the studies are presented.

3.1 Research approach

The research on design through constructing artifacts has interested the HCI and the interaction design community in particular for over a decade (Fallman 2003, Zimmermann *et al.* 2007, Forlizzi *et al.* 2008, Koskinen *et al.* 2011). The interest has aroused naturally alongside experienced evolutionary expansion in the scope of the HCI field from usability to human experience that requires both design thinking and research (Zimmerman & Forlizzi 2008). As Koskinen *et al.* (2008) stated, the line between design and its research is ambiguous. According to Fallman (2003), design orientation in HCI research means that researchers need to be involved in creating and giving form to something that does not exist yet. He called this activity *research-oriented design* (Fallman 2003). Zimmerman *et al.* (2007) base their *Research through Design* (RtD) model on Frayling's (1993) writings about the need for a method for understanding how research can be achieved through art and design. It is an approach for conducting scholarly research that engages the knowledge of design practice, such as methods, practices, and processes, to be able to generate new knowledge (Zimmerman & Forlizzi 2014). The approach provides four criterion for evaluating the contribution of the RtD process: first, the *invention* has to be significant; second, the researcher needs to document the *process* in detail to enable other researchers to repeat the studies; third, peers should be able to reproduce the results (*relevance*); and fourth, others should be able to build on the resultant outcomes (*extensibility*) (Zimmerman *et al.* 2007). According to Zimmerman and Forlizzi (2008), the benefit of this approach is that by exploring different materials' design researchers can actively and intentionally construct the future and not let the present and past limit their creativity. The intention for RtD is based on some philosophical stance, which can come from researchers' own observations and reflections on the preferred state to

be, but it can also come from real-world problems that force the researcher to concretely frame the problem for a certain context of use (Zimmerman & Forlizzi 2008).

The research through design approach has been criticized during the years by Stolterman (2008), Zimmerman and Forlizzi (2008), Zimmerman *et al.* (2010), and Gaver (2012). For example, the developers of the approach, Zimmerman and Forlizzi (2008), refer to Cross (2001) who do not distinct works created through normal design practice as research contributions. They created restrictions for the approach by limiting it to cover only contributions to novel integrations of the problem and not just incremental modifications of products that already exist on the market (Zimmerman *et al.* 2007, Forlizzi *et al.* 2008). Wiberg and Stolterman (2014) attempted to move toward systematically tracing the design concepts to ensure that the proposed design is novel. But, as Stolterman (2008) stated, the design is about being unique and particular, as the goal of the design is to create something non-universal, for a specific purpose, situation, client/user, with specific functions and characteristics, and requiring a limited time and resources (Stolterman 2008). Thus, the novelty aspect of the artifact created can be quite challenging to achieve. It significantly limits the acceptable contributions, as everything has been invented already in HCI or in some other discipline. Thus, the acceptable contribution should be also a recreation or an iterated version of something that has been investigated or designed before. As Gaver (2012) recently pointed out, a new design sets the stage for the development of variations, recreations, reconsiderations, and fresh beginnings. He also expressed skepticism regarding design research community theory builders' eagerness to suggest normative standards and convergence on how the research should be conducted and what can be counted as RtD. Instead, he suggested that the community should focus on exploring, speculating, particularizing, diversifying, and manifesting the results in the form of new conceptually rich artifacts. (Gaver 2012.)

Koskinen *et al.* (2011) summarized the problems encountered with the research through design model and thus decided to use a *constructive design research* term instead. They also highlighted that constructive design researchers require flexibility with methods and theory and should not be forced to follow a certain method or framework. According to them, constructive design research is a better definition for the process where the construction of an artifact is the key element of the research and in constructing knowledge from the research (Koskinen *et al.* 2011) As Gaver (2012) stated, research through design should be appreciated for its rapid increase in new realities and its central achievement being the artifacts. He

presented four common values that people working in RtD seem to share: pursuing user-centered design, exploring a large variety of potential designs for a good outcome, appreciating craft and detail in the work, and understanding that the practice of making is the way to make discovery (Gaver 2012).

As the HCI design research community still struggles to define the correct criterion for suitable contributions and has contradicting views on the RtD approach, the author decided to choose a combination of research-oriented design (Fallman 2003), RtD (Zimmerman *et al.* 2007), and constructive design research (Koskinen *et al.* 2011) for the research approach for this thesis, as in all three, the design is seen as a matter of making something and through that activity new knowledge can be achieved. They are also suitable for investigating visual design issues by constructing new artifacts. All of them are meant to be used in design research dealing with HCI. In all approaches, artifacts are central to the knowledge contribution of these methods. As Fallman (2003) stated, through the construction of an artifact, the process should be able to contribute some sort of truth or knowledge, which would not be achievable without the designed artifact. The artifact can be almost anything: a prototype, scenario, a mock-up, or a detailed concept to be constructed. Regardless of the form of the imaginative items, they are representatives of the actual product and can be presented as verbal descriptions, sketches, and images or highly polished prototypes (Koskinen *et al.* 2008). In this thesis, the combination of three constructive design research approach is used for both solving very detailed UI problems through design and creating a method for other researchers to use when trying to understand AUXs, needs, and wishes for visual UI design in the early development phase.

3.2 Focus and development phases of the studies

The thesis contains seven user studies (Table 2). Studies 3, 6, and 7 (II, IV, & III) focused on understanding more holistic AUXs with the studied artifacts. Studies 1, 2, 4, and 5 (V, VI, VII, & VIII) concentrated on studying smaller and more detailed visual UI design issues. The first study (V) focused on visual design aspects of a mobile phone GUI of a social media application in which the user location is indicated visually on a map. The following studies from 2 to 6 (VI, II, VII, VIII, & IV) focused on 3D GUI and VE design on tablet-sized touchscreen devices. In study 2 (VI), the focus was on studying 3D GUI icon design. In study 3 (II), emphasis was on 3D GUIs visual and interaction design. In study 4 (VII), visual indication of the shared and target objects while moving objects between private

Table 2. User studies of the thesis. * E= experiment, C= concept phase, ED&D= early design & development phase, PL= pre-launch, AL= after launch. ** Q= questionnaire, S-SI= semi-structured interview, O+V= observation with video recording, S-EDT= self-expression drawing template. * MM= mixed-methods, QM= qualitative methods, MT=methodological triangulation. ****ViDE= visual design example.**

Study & theme	1. Location indicators	2. 3D icons	3. 3D GUIs	4. 3D UI for sharing 3D objects	5. Indication of 3D objects	6. 3D VE for tourism marketing	7. Wearable tangible UI
Publication	V	VI	II	VII	VIII	IV	III
Setting	Survey	Lab	Lab	Lab	Lab	Lab	Lab
Development phase *	C	C	C	ED&D	ED&D	1 st E: PL, 2 nd E: AL	1 st E: C, 2 nd E:ED&D
Participants/ % of male	106/ 77	40/ 63	40/ 63	30/ 66	35/ 69	21/ 21/ 47 53	16/ 15/ 32 60
User study methods**	Q, ranking	S-SI (pair), O+V, Q, 5-point scales	S-SI (pair), O+V, Q, 5-point scales, S-EDT	S-SI, O+V, Q, 5-point scales, ranking	S-SI, O+V, Q, 5-point scales, ranking	S-SI, O+V, Q, 5-point scales	S-SI (pair in 1 st E), O+V, Q, 7-point scales, S-EDT
Main study approach ***	MM	MM	QM+ MT	MM	MM	QM	MM+ MT
Artifacts****	ViDEs: 13 (1st task) 11 (2nd task)	ViDEs: 1-3 (1 st -5 th task) on tablet	ViDEs: 4 use cases on 15' laptop	Functional prototype on 24' PC, ViDEs on paper	Functional prototype on 12' touchscreen laptop, ViDEs on paper	Functional prototype: on 12' (1 st E), 13' (2 nd E) laptop	1 st E: ViDEs 4 sketchy use cases on 40' TV, 2 nd E: functional prototype, ViDE use case on 13' laptop
UX study focus	Visual GUI icon design	Visual GUI icon design	Visual GUI, interaction design	Visual GUI, interaction design	Visual GUI, interaction design	Visual GUI, interaction design	Physical UI, interaction design

and public virtual spaces was explored from interaction and visual design points of view. In study 5 (VIII), the visual indication of moved- and target-objects in a VE was investigated from interaction and visual GUI design points of view. In study 6 (IV), a 3D UI designed for travel location marketing was explored from GUI and interaction design perspectives. In study 7 (III), a wearable and tangible UI was investigated from physical GUI and interaction design perspectives.

Most of the studies were conducted in concept (C) or early design and development (ED&D) phases in which use is anticipated. Studies 1, 2, 3, and 7/ E1 (V, VI, II, & III) were conducted in the concept phase. In the concept phase, the design is still exploratory and several designs are produced systematically. Studies 4, 5, and 7/ E2 (VII, VIII, & III) were conducted in the early design and development phase. In this phase, the design for technical development has been selected and the development has been started. Only study 6 was conducted in later development phases. Study 6/ E1 was conducted in the pre-launch (PL) phase, and study 6/ E2 in the after launch (AL) phase. In the pre-launch phase, the design and implementation work is complete and only minor changes will be done after the user evaluation. In the after launch phase, the product is already on the market and thus ready from the design and development point of view, but if changes are needed, they will be implemented later and revised with new releases or updates. (Table 2.)

The research process for the whole thesis is presented in Fig. 2. Figure illustrates when user studies 1–7 were conducted and when their results were

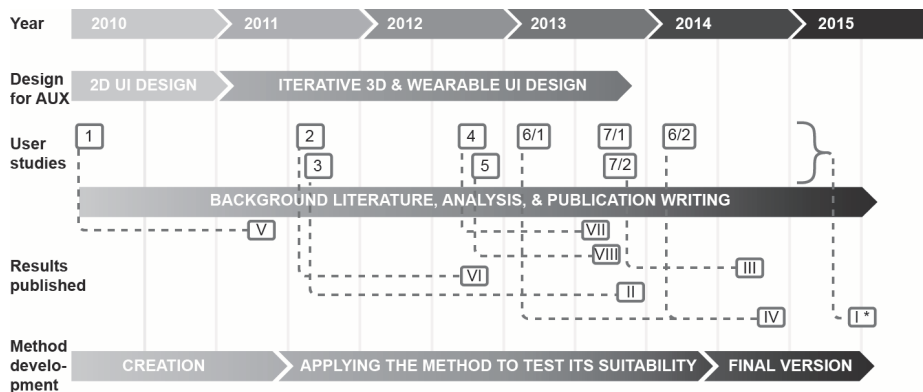


Fig. 2. Research process of the thesis and when the studies were conducted and the results published. *) Manuscript combining all the studies submitted to for review in the beginning of August 2015.

published in publications I–VIII. It also shows when the AUX design was done as well as the collection of the background literature, the analysis of the results, and the writing of the publication. In addition, it illustrates the development phases.

3.3 Artifacts

In this thesis, the artifacts were different visual design examples (ViDEs) created and studied in the six experiments: 1, 2, 3, 4, 5, and 7 (V, VI, II, VII, VIII, & III). They ranged from *sketches* to *tidy computer-generated illustrations* and were created by using the initial version of the method depicted in Fig. 3. The method is an artifact itself and was constructed in study 1 (V) to create the ViDEs and evaluate them in the AUX studies. The method was utilized and applied in studies 2, 3, 4, 5, and 7 (VI, II, VII, VIII, & III). It was used to create examples for all user studies, both individually in studies 1, 2, 4, and 5 (V, VI, VII, VIII) and in parallel with larger user-centric design processes, such as industrial design process (Ulrich & Eppinger 2012) in studies 3 and 7 (II, III).

The method’s suitability for different design and evaluation cases was explored in the studies. In studies 3 and 7 (II & III), the aim was to determine whether the method can be used to study larger visual UI and interaction design aspects. In studies 1, 2, 4, and 5 (V, VI, VII, & VIII), the aim was to assess the method’s suitability for investigating detailed UI design issues. Study 6 (IV) was included in this thesis as a comparison study, as it was conducted without using the method and ViDEs; thus, it was possible to perceive the change what ViDEs and method can make for the studies.

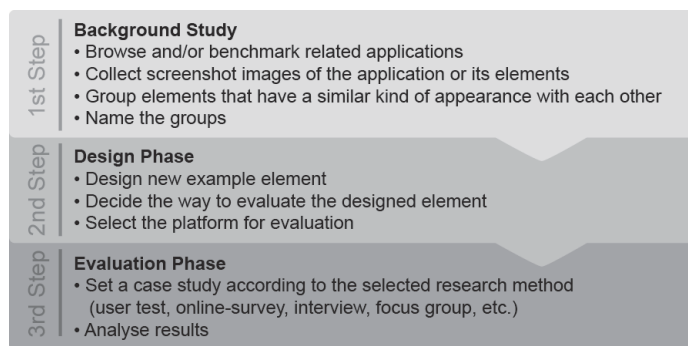


Fig. 3. Initial method for creating ViDEs for AUX evaluations (V).

The basic principles of the method are divided into three subsequent steps (Fig. 3). In the first step, the background information of the design area is gathered by searching for and browsing existing or related applications. In this phase, screenshot images are taken either of the whole application's visual design or some smaller elements of it. Next, the collected images are clustered based on the visual similarity of the appearance and then the formed clusters are named. In the second step, a new design/s is/are created. The evaluation method and the platform are also selected. In the third step, the user study is conducted by following the selected study method/s and, finally, the findings are analyzed.

Tidy computer-generated example images were created in Photoshop or Illustrator for studies 1, 2, 3, 4, 5, and 7 (II, III, V, VI, VII, & VIII). Comparable visual design examples were created by adding different visual effects on the interactable objects on the screenshot image taken from the functional prototype in studies 4 and 5 (VII & VIII). Separate ViDEs were drawn in Illustrator in study 1 (V). In studies 2 and 3 (VI & II), the 3D models for the example images were constructed in Blender. 3D models for the *step-by-step use cases* for study 3 (II) were modeled first in Blender. Then for each step, the image was rendered out and added to an image of the target application screenshot in Photoshop. Tidy computer-generated examples for study 7/ E2 (III) were drawn in Illustrator and the images were added to dimmed pictures of the use context in the Photoshop (Fig. 4, b). Sketches for study 7/ E1 (III) were hand drawn, and the separate images were constructed in PowerPoint as an animated use-case story in which the background context was presented as Illustrator drawings (Fig. 4, a).

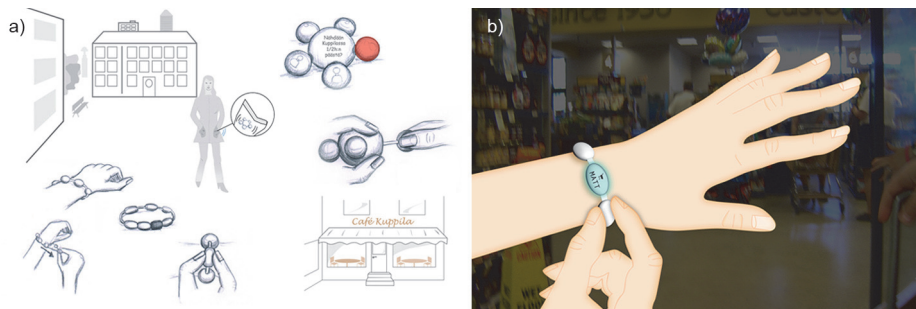


Fig. 4. ViDEs: a sketch (a) and a tidy computer-generated illustration (b).

The presentation format of the examples varied between the studies (Fig. 5). In studies 1 and 2 (V & VI), the examples were shown as static pictures either on a

computer screen (Fig. 5, a) or on a 10-inch tablet device (Fig. 5, b). In studies 3 and 7 (II & III), the use-case stories were presented either on a 15-inch computer screen (Fig. 5, c & j) or on a 4-inch TV (Fig. 5, i). In studies 4 and 5 (VII & VIII), ViDEs were on 12-inch paper and were presented side-by-side on the table (Fig. 5, e & g). Compared to the functional prototype's screen size, the ViDEs were smaller in study 4 (VII) (Fig. 5, d-e) and equal in study 5 (VIII) (Fig. 5, g).

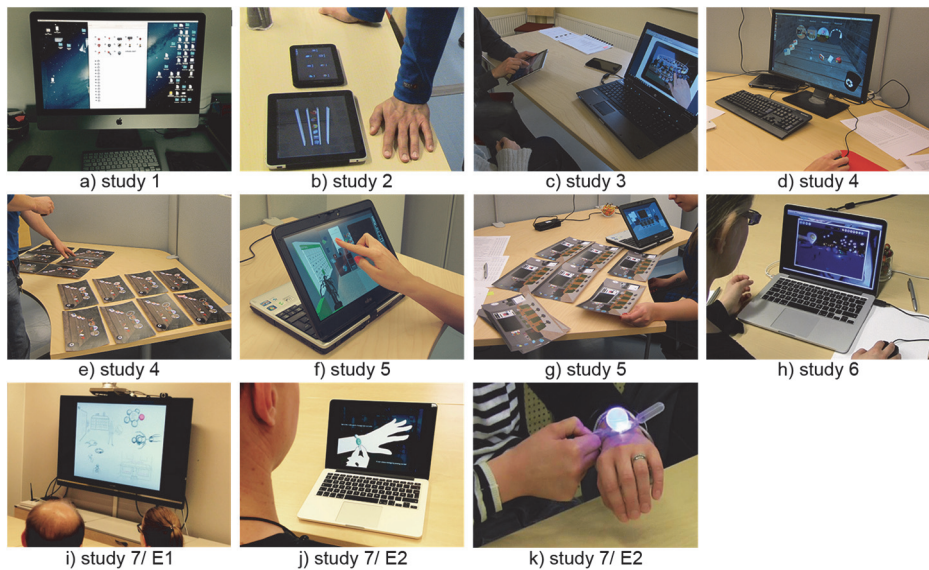


Fig. 5. Artifacts used in the studies and presentation format of ViDEs.

ViDEs were used independently in studies 1, 2, 3, and 7/ E1 (V, VI, II, & III) (Fig. 5, a-c & i). In studies 4, 5, and 7/ E2 (VII, VIII, & III), they were used in addition to a functional prototype to study certain GUI aspects in more detail (Fig. 5, e & g) (VII & VIII) or to present the finalized design (Fig. 5, j) of the functional prototype (Fig. 5, k) (III). In study 6/ E1 & E2, only functional products were used (Fig. 5, h).

3.4 Study settings

The study settings varied according to the goals of the research. As the aim of the first study (V) was to explore users' preferences and their use habits of map-based social media applications and services, it was conducted as an online survey. A

survey is a well-defined set of questions to which respondent is asked to respond individually with no researcher present (Lazar *et al.* 2010). A survey approach was selected because it is a relatively fast and low-cost method that enables responses to be collected from a geographically dispersed population of subjects and the results to be quantifiable (Lazar *et al.* 2010). Survey participants were from three university cities in Finland: Rovaniemi, Oulu, and Helsinki, which are located hundreds of kilometers from each other.

The laboratory setting was selected for studies 2–7 (VI, II, VII, VIII, IV, & III), as the aim of the studies was to gain a more comprehensive understanding of users' experiences, needs, and wishes for the design. Moreover, in a laboratory setting it was easier to present the prototypes and example images in as controlled setting as possible for each subject. As Koskinen *et al.* (2011) explained, laboratory studies are valuable because it is possible to focus subjects' attention on the studied aspects, to study the relation between interaction and experience, and to compare hypotheses. Laboratory studies were also selected because it was not possible to conduct field studies due the limitation of the functional prototypes and other research material. In laboratory studies, it is also easy to record observations and measurements (Koskinen *et al.* 2011). The setting was not an actual usability laboratory, but a typical office space or a meeting room (Fig. 5). The intention was to create as relaxed atmosphere as possible for the participants to reduce their anxiety caused by the evaluation context and its effect on their experiences (Arhippainen 2009). Most of the studies were conducted with a single participant, but studies 2, 3, and 7/ E1 pairs evaluated prototypes together. Pair evaluation enabled participants to discuss the studied aspects together rather than simply answer the researcher's questions.

3.5 Data collection methods

Research materials for this thesis were collected in seven UX studies described in the prior section. In studies 1, 2, 4, 5, and 7 (V, VI, VII, VIII, & III) data collection followed a *mixed-methods approach* (Creswell & Plano Clark 2011), as both qualitative and quantitative data were collected. The studies utilized *qualitative priority*, which means that the emphasis was on qualitative methods, and quantitative methods were used to aid them and played a secondary role in data collection. The research design for these studies followed *the convergent parallel design*, as both types of data were collected and analyzed in parallel and then compared, and their relation was questioned and the final interpretation of the data

was formulated (Creswell & Plano Clark 2011). Purely qualitative data were collected in studies 3 and 6 (II & IV). *Methodological triangulation* (Lazar *et al.* 2010) was used in studies 3 and 7 (II & III), meaning that multiple methods were used for collecting data from the same phenomenon (Lazar *et al.* 2010).

3.5.1 Survey

In the online survey, a questionnaire with both open-ended and closed-ended questions was used. The main idea of close-ended or fixed-response questions is to register the strength of a respondent's opinion on the given choices. Open-ended questions, in which subjects can respond in their own words, help respondents to highlight the most relevant issues of the topic (Jordan 2000). The idea of open-ended questions was to gain a better understanding of the studied aspects and provide a rationale for the selection task results. The questionnaire also included unordered questions for collecting detailed information on subjects' prior experience with technology and background. It also contained a quantitative ranking task of visual examples, in which the best, second-best, and third-best options from given example designs were ranked by the subjects. The survey structure was the following: background questions, more general questions of preferences, and ranking task questions with ViDEs.

3.5.2 Laboratory studies

In the laboratory studies, participants were asked to complete a consent form and a short questionnaire at the beginning the evaluation, which had questions on subjects' background and prior experiences with technology. The actual data collection methods used during the evaluation were semi-structured interviews and observation. Semi-structured interviews were selected as the main data collection method because interviews are viewed as the best technique to use when studying UXs and trying to understand them holistically (Goodman *et al.* 2012, Arhipainen 2009). According to Brinkmann and Kvale (2015), qualitative interviews are also a good method for understanding how a subject sees, feels, and understands the world. In semi-structured interviews, it is essential to have reflection and exchanges between the researchers and participants that may require prompting the participants, rephrasing questions, and making changes according to the interview situation (Galletta 2012). This is also referred to as laddering (Jordan 2000). The idea in semi-structured interviews in these studies was to get users' feedback on the

presented designs with AUXs and users' needs and wishes for the visual design aspects of the studied UI. The studies were planned in a way in which subjects were introduced to the topic and then moved into more detailed aspects of it. As Goodman *et al.* (2012) stated, a UX interview should start with more general questions and end with more detailed ones. To record subjects' comments and observe their interaction with the artifacts, sessions were recorded on video and notes were written down on an observation form designed specifically for each study.

Quantitative methods were used in parallel in studies 2, 4, 5, and 7 (IV, VII, VIII, & III). In studies 2, 4, & 5 (IV, VII, & VIII) quantitative data were collected in the form of short questionnaires with 5-point ordered scales measuring different features of the presented artifacts. In study 7 (III), AttrakDiff™ (2015) inspired 7-point semantic ordered differential word-pair scales were used. The AttrakDiff™ method was developed for measuring interactive product attractiveness (Hassenzahl *et al.* 2003). In the method, the semantic word pairs are presented either in English or in German. As these were not study participants' native languages, the words were translated into Finnish because the author believes it is more difficult to express an exact feeling or exact experience in a non-native language. Some of the original words were not suitable for the purpose of the evaluation and were changed to more suitable ones. Alternative words were found from words presented in the *Product reaction card method* (Barnum & Palmer 2010) and an applied version of it (Sunnari *et al.* 2012). Similar ranking tasks to the study 1 survey were utilized in studies 2, 4, and 5 (IV, VII, & VIII). In the ranking task, subjects needed to select the best, second best, and third best options from the given example designs.

To be able to gain a better understanding of users' experiences, wishes, and needs as well as to obtain the most reliable results possible, methodological triangulation was used in studies 3 and 7 (II & III) through the *Self-Expression Template* method (Arhippainen *et al.* 2013). The idea was to allow participants to express their hidden needs and wishes nonverbally by drawing on a paper template specifically designed for this case. Participants were given colored pencils and asked to draw on the given template. In study 3 (II), they were asked to draw their own 3D UI on an A4-sized template that presented a natural-sized tablet device frame without a screen (Fig. 6, a). In study 7/ E2 (III), subjects were asked to draw their version of the tangible and wearable UI on a template with a line drawing of a human hand and arm (Fig. 6, b). They were also asked to mark on a miniature human figure (in the left bottom corner of the template) the best place for wearable

technology (Fig. 6, b). The template task was the last task in the evaluation to ensure that the subjects had been properly introduced to the topic.

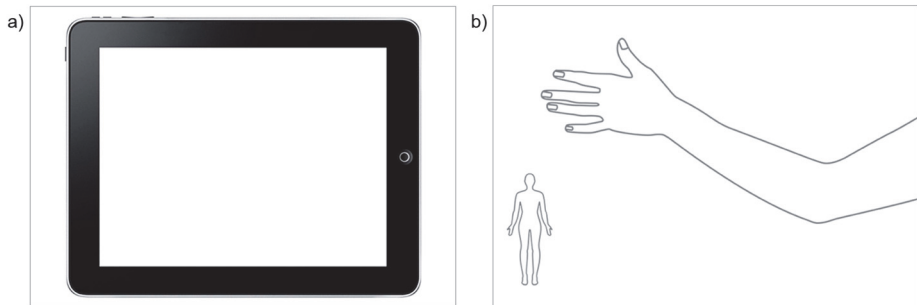


Fig. 6. Self-expression templates used in studies 3 (a) and 7/ E2 (b).

3.6 Participants

A total of 324 participants were included in the studies in this thesis. However, some of the participants took part in several studies that were run in parallel (2 & 3, 4 & 5); thus, the actual number of different subjects is 254. The number of participants varied between studies from 15 to 106. In the first study (V), 106 respondents participated. In laboratory evaluations, the number of participants varied from 15 to 40. Forty subjects participated in studies 2 and 3 (VI & II). In study 4 (VII), there were 30 participants. Thirty-five subjects participated in study 5 (VIII). In both experiments in study 6 (IV), twenty-one subjects participated. In the first experiment of study 7 (III), there were 16 participants, and in the second experiment there were 15. (Table 2.)

The participants represented a convenience sample in every study, as they were recruited from the best available target user group of people. A target user group is the possible future users of the systems. Participants were recruited via email, friends, and colleagues, Facebook, Patio living lab user community (Patio 2015), or face-to-face. As most of the participants were either working or studying in a university or polytechnic school, they were easily accessed. Which subjects were selected for each evaluation depended on the intention of the study. In studies 1 and 3 (V & II), it was essential to have prior experience with the studied technology, but in experiments 2, 4, 5, 6, and 7/ E1 & E2 (VI, VII, VIII, IV, & III), it was not that important, as novice users were the target group. The participants were not

equally distributed by sex, as in all studies except 6 (IV) and 7/ E1 (III), the number of men was greater, ranging from 53% to 77% (Table 2).

3.7 Data analysis methods

In the data analysis, both qualitative and quantitative methods were used. Interview and observation data as well as open-ended answers to the survey were analyzed by applying the *general qualitative coding* method (Charmaz 2008). The coding method is based on a grounded theory open coding approach in which the data are closely read and questioned (Charmaz 2006, 2008). If the coding of data does not directly follow the grounded theory approach, Charmaz (2008) suggested calling it general qualitative coding. The idea of the coding method is to identify topics for writing the results, which can be used to sort and synthesize the research material. These identified topics are then used for categorizing the data until saturation is reached, e.g., no new themes will arise anymore from the data (Charmaz 2008).

The data analysis for each study began right after the experiment involving handwritten observation notes, and if something was missing from the notes or specifications were needed, then video recordings were analyzed. Video recordings were used to understand the relationship between a subject's comment and the interaction context in which the comment was made and also to capture their direct comments for the reporting of the results. The coding of the text was done with colored markers or pencils. The qualitative coding of data was done by the author alone, except when analyzing self-expression template drawings, then coding was done together with another UX researcher. The reason for analyzing the data alone was twofold. First, the time and money constraints in the project and the availability of the other researcher made it so that only author was able to do the data analysis. Second, the author wanted to use her intuition as a designer and thus focus the analysis on aspects that might not be evident for a coder who is not a designer in the specific field. During the process, the author was the only design researcher in the teams. The author wanted to focus the analysis on matters that were indicated by many subjects, but also on comments that were made by only one subject, if they were offering new insights for the design. By coding like this, the author wanted to obtain the richest possible image of user needs and wishes for the design.

Self-expression template drawings in studies 3 and 7/ E2 (II & III) were analyzed qualitatively by applying the affinity diagram method (Beyer & Holzblatt 1998). According to Beyer and Holzblatt (1998), when constructing an affinity diagram, all the individual notes written during the analysis and interpretation

process are organized under different topics and hierarchies. The affinity diagram method was applied in the analysis because it is suitable for data that contain a lot of individual notes, even more than 200 notes (Beyer & Holzblatt 1998). The analysis of drawings began by simply looking at individual drawings and collecting each item or idea that subjects had drawn or written on the template. Ideas were written on the same-colored post-it notes. In this phase two researchers individually analyzed the drawings. After collecting ideas, researchers looked together what subjects had stated about their drawings from the observation notes and video and added notes if something was missing. Then two researchers started to categorize post-it notes together under different mutually defined topics. As suggested by Beyer and Holzblatt (1998), researchers did not use predefined categories in the organization of the notes, but allowed individual notes to suggest to which category they might belong. After the first categorization round, the categories were defined based on their topics and indicated with different colored post-it notes. The names were chosen based on a mutual understanding between researchers. Next, each note from a formed category was reviewed again, and if it was possible to re-organize notes under more specific sub-topics, this was done. If categories were too similar, they were combined. This was done until saturation was reached, e.g., no new sub-categories were found.

To analyze the quantitative scales and ranking tasks, quantitative methods were used. Suitable statistical analysis methods were selected for the analysis based on the sample size and the variables used. As the samples were relatively small and non-normally distributed, the Kruskal and Wallis (1952) test was used in studies 1 and 4 (V & VII). In study 7/ E1 & E2 (III), the Wilcoxon signed rank test (Wilcoxon 1945) (III) was used. The author was not in charge of analyzing the quantitative data.

4 Results

In this section, the results are presented. In the Table 3, summary of the contribution of the studies for both the EDE method and UI design are presented.

Table 3. Summary of contribution of the studies for the EDE method and UI design.

Study Publication	Contribution for the EDE method	Contribution for the UI design
1 (V)	Initial version of the method and its applicability in 2D UI design case and in an online survey.	User preferences on how user's own and friend's location should be visually presented on a map based mobile social media applications.
2 (VI)	Pros and cons of the method for comparing designs against existing products with a focus on smaller quite detailed GUI design aspects.	AUXs, user needs and wishes for 3D UI icon design.
3 (II)	Pros and cons of the method for early design and development phase studies conducted with tidy computer generated use case stories.	AUXs, user needs and wishes for 3D GUI design.
4 (VII)	Pros and cons of the method in a detailed UI design case with high amount of examples presented on paper.	AUXs, user needs and wishes for visual indication while sharing objects from private 3D UI to public 3D VE.
5 (VIII)	Pros and cons of the method in detailed UI design case (visual effects) with high amount of examples presented on paper.	AUXs, user needs and wishes for visual indication while moving objects in a private 3D UI.
6 (IV)	Highlights the need for the method also in the later development phases.	UXs, user needs and wishes for a web based 3D VE for travel destination marketing and confirmed findings of studies: 3, 4, and 5.
7 (III)	Pros and cons of the method in early evaluations with concept sketches presented as use case stories as well as a tidy computer generated use case story for extending the limited functional prototype.	AUXs, user needs and wishes for design of tangible, wearable, and deformable UIs.

Sub-section 4.1 presents the summary of how AUXs, needs, and wishes can be studied in the early development phase (RQ1). The summary of suitable ViDEs and how they can be created (RQ1a) is presented in 4.1.1. In 4.1.2, the benefits of the visual design examples in the evaluation of anticipated user experience at the early phases of research and development (RQ1b) are summarized. In sub-section 4.2, the summary of how interactive objects of both virtual and physical UIs should be visually designed to be able to draw users' attention to them (RQ2) is presented. In 4.2.1, the solutions for increasing the visibility of an interactive object in the UIs are described (RQ2a). Finally, in 4.2.2, the impact of the context for an object's visual design is explained (RQ2b).

4.1 The EDE method

AUXs and users' needs and wishes for a visual UI design can be studied in the early development phase with different kinds of visual design examples created through the EDE method introduced in publication IV and finalized in publication I (Fig. 7). The iterative EDE method was named after its three subsequent steps: explore, design, and evaluate.

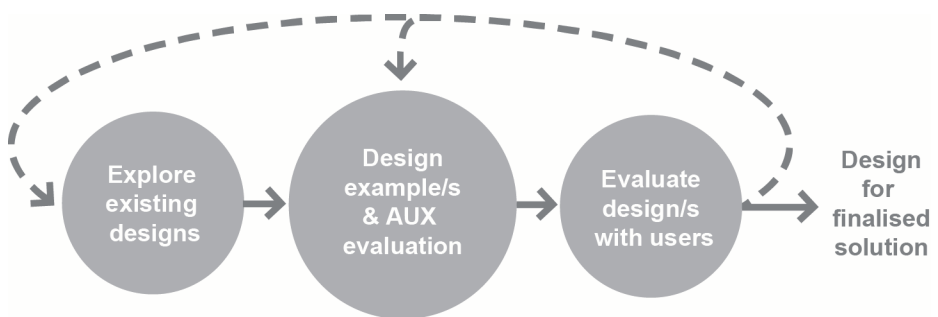


Fig. 7. The EDE method for creating ViDEs and evaluating them in early development phase AUX studies.

In the exploration step, inspirational and state-of-the-art images of the design area is searched from the web, research papers/reports, and patents. When the EDE method is used, the existing designs can be used in two ways. First, they can be used for charting user preferences of existing visual key styles. The results will then be user preferences for the existing design styles and can be based on users' prior experiences with the existing technology. Second, existing designs can be used as

inspiration for new ideas, such as benchmarks. In this case, the existing design can be applied more loosely to be able to develop something new. In cases of radical innovations (Diederiks & Hoonhout 2007), it is not possible to have an existing design in that certain area, as the technology does not exist yet; thus inspiration can be found from related technology fields or even from some other areas of design, such as architecture. Images of identified concept designs and existing or related products are collected intuitively based on the research topic. Then the collected images are interpreted, e.g., learned from prior art and research. Collected images can be categorized under different topics according to the visual style of one element or the overall design of the artifact to determine the visual key styles used or emerging trends. This can be a joint activity involving designers and researchers.

In the design step, example designs for the AUX evaluation are created and an evaluation is planned. Created examples should allow participants to focus on specific aspects under research; thus, only one element should be varied between different examples. If the focus of the study is the whole GUI design style, the whole GUI design needs to be varied between different examples. If some design feature is to be added to an existing GUI design, then the varied design feature should be laid onto image of an original GUI design. Due the comparability of the examples, the varied aspects need to have a uniform color theme. The number of examples, the presentation technique, and the format are selected based on the study topic and context. Next, the study approach, setting, data collection methods, and procedure are planned and the necessary materials are prepared. The activities are divided between a designer and UX researcher. The design is done by the designer and evaluation planning by the UX researcher.

In the evaluation step, the evaluation is set up and a pilot study is done. In the actual evaluation, participants are asked to comment aloud and elaborate on their answers to avoid misinterpretations in the analysis phase. The order of created example images needs to be changed for each participant. In data analysis, users' needs and wishes should to be assessed by specialists to avoid creating UIs that are difficult to use.

As the process is iterative, it can begin again with a new research topic, and the outcome of the prior processes can be used as a basis of user needs. Therefore, it allows an iterative design in which the knowledge grows through the iteration rounds. This also permits the process be start again from the beginning or from the design step if the results did not reveal differences between the studied examples. If sufficient data were obtained, the process ends and a finalized design for the technical implementation is created.

4.1.1 Visual design examples

Both kinds of examples can be used in early phase AUX studies: sketches (III) and tidy computer-generated illustrations (II, III, V, VI, VII, VIII). The presentation technique depends on the studied aspects and design target.

Sketches were found to be suitable for studying service ideas, 3D space interior designs, product forms, and anticipated interactions in the concept design phase (I, III). Sketches allowed different options to be evaluated critically, as participants were aware that they are not evaluating the final design (I). In addition, sketches left room for the imagination, as subjects were able to express their needs and wishes for the design while evaluating them (I, III). However, they are not suitable for studying visual UI design aspects, as in a sketch presentation, the level of detail is not sufficiently high to allow participants to see the future design in a reliable and evaluable manner (I). Individual sketches are also always unique; therefore, the creation of detailed comparable examples is difficult and time consuming (I). Thus, to study detailed visual UI design aspects in the early design and development phase, it is better to use tidy computer-generated evaluation examples (I, II).

Tidy computer-generated example images were found to be suitable for studying large GUI design problems (I, II), comparing very detailed GUI design aspects (V, VI, VII, VIII), and comparing designs against existing products (VI) in the early concept phase. They were useful because they allowed participants to focus on indented aspects of the UI design and select a suitable solution for the indicated UI design problem without needing to invent their own solution for it. They were also perceived as closer to functional prototypes when a visual design of a UI was in focus, as they allowed participants to concentrate only on the visual design without becoming distracted by worrying about how to interact with the functional prototype (I, IV).

The number of example images depends on the study problem. One ViDE can be used if the purpose is to present a use case and collect AUX information on the finalized concept idea (III). It can also help participants to see beyond the bulkiness and unfinished look of the functional prototype (III) and allows them to focus on desired aspects of the prototype (I, III). Two or more examples can be used to explore the concept space (II, III), charting UXs with different design alternatives (II, III, V, VI, VII, VIII), and finding suitable solution for the next iterative design phase (II, III).

The presentation format of ViDEs can be almost anything that is available, such as on paper (VII, VIII), a computer screen (III, V), a large-screen TV (III), or on a

target device (VI). When compared to each other, the paper examples (VII, VIII) were found to be worthy, as they made it easy to counterbalance the options for every subject and allowed subjects to hold the examples in hand when comparing them. Computer screens and target devices allowed examples to be shown in authentic size (II, VI). The survey limited the possibility to show examples in the intended size and quality, as it depends on the subject's device that s/he uses to respond (I, V). The target device context gave the impression of a realistic context of use for the subjects, but it did not allow examples to be compared side by side (VI).

The comparability of examples can be eased with design. To ease the comparison process, the example images should be created with a uniform color theme (I, II, V, VII, VIII), presentation technique (I), size, and style (I, V). Examples should also be created by a single designer to prevent different visualization styles and tastes from affecting their comparability (I). If examples are compared to existing designs in a certain application context, the created examples need to be visually on the same level as the existing designs and similar in size (I, VI, VIII). Moreover, if a certain object in a UI is studied with ViDEs in parallel with functional prototypes, then the application context should be clear and evident in the examples to allow subjects to evaluate how the suggested design would look in the final application (I, V, VII, VIII).

4.1.2 Benefits of visual design examples in AUX studies

ViDEs allowed participants' attention to be focused on the studied aspects (I, III, VI). They enabled the implemented prototype's visual design to be extended and detailed GUI design aspects to be studied (I, II). ViDEs also allowed subjects to evaluate the anticipated interaction (II, III) and object behavior (animations) (VI) in the concept design phase. Examples presented as a step-by-step use-case image series (II, III) allowed larger concept and visual design issues, anticipated interaction, and hierarchical structures in the example design cases to be studied.

ViDEs also helped subjects to anticipate the final design over the bulkiness and visual unpleasantness of the functional prototype (I) and evaluate the pleasantness of the final visual design (III). Most importantly, they allowed the visual design of an object or UI to be discussed with the investigator in the early development phase in a reliable manner, without interpretation errors, as participants could see the possible future designs (I, II). They also acted as shared reference points in the evaluation between participants and researchers (I). Thus, they were able to prevent

possible interpretation errors that might occur when only oral expressions are used (I).

ViDEs, both sketchy and tidy computer-generated ones, were faster and more cost-effective to produce than functional prototypes (I, II, VI, VII, VIII). Tidy computer-generated example images were perceived to be able to reveal problems with the visual appearance, interaction and usability of the design, before any implementing and development hours are spent (I, II). The results gained with paper-based example images in studies 4 and 5 (VII, VIII) were confirmed in study 6 conducted with the functional prototype (IV), and thus the initial findings were reliable (I). Furthermore, as example images were able to deliver the feeling of empowerment for subjects to change the final design, consequently, important user feedback was gained for future designs and research efforts (I, II, VIII).

Although the EDE method and example images created with it were developed and mainly used in the concept and early development phase, they could also be helpful for UX studies conducted in later development phases and could also be used in studies conducted with launched products to gain knowledge for the redesign and next version of the products (I).

4.2 Visual design of interactive content in the example UIs

The visual notability of interactive elements in both virtual and physical user interfaces depends both on the visual design of objects (RQ2.1) and their use context (RQ2.2), e.g., application or physical context. In general, interactive elements in 2D, 3D, or wearable UIs should visually stand out from the non-interactive content. One possible solution for 3D UIs is highlighting the interactive 3D elements with a visual cue, such as an animated glow effect (II, IV, VII, VIII), to be able to draw users' attention to them. In physical UIs, the visual design of input and output objects should indicate their different functions (III). In the following sub-sections, these findings are presented in more detail.

4.2.1 Means for increasing the visibility of an object in studied UIs

The design of an object can indicate its interactivity. The design of shapes, color, and animated features of a 3D icon can make it stand out from its background context and other icons (IV, VI). If animations are used, then the design needs to be very carefully done. In studied 3D VEs, 3D object animations were perceived to have two functions; drawing users' attention (VI) and indicating content that the

icon offers, such as movement to another location (IV). If animations in 3D objects are used infrequently, then they should have a clear function, for example, indicating that an application is shutting down or entering a message (VI). In addition, animations should not be merely used for eye candy, as they might be annoying and even cause dizziness (II, VI).

Visual indication should be used when users' attention needs to be drawn to interactive content within 3D VEs (III, VII, VIII). This is particularly important in the case of novice users and within use contexts in which the information needs to be found quickly, such as marketing or more work-oriented 3D VEs (IV, VI, VIII). The distinguishable glow effect is suggested as a solution in cases when a user enters into an unfamiliar 3D VE to show interactive 3D content, particularly if the interactive content visually blends too well with the other objects and content within the 3D VE (IV, VIII) (Fig. 8, 1-2s). After an animated pulsating glow effect ranging from 0–4 pixels in size within a 5-second timeframe (Fig. 8) was implemented in the functional prototype, it doubled the amount of interactive 3D elements identified within the UI in the first glimpse (IV). In the later phase of the study, over 90% of the subjects noticed the effect and it was interpreted as the interactiveness of elements (IV). However, the visual indication does not need to be shown all the time. It can be shown only for a limited time after entering into the VE or it should offer the possibility of either switching it off or adjusting the amount of the glow (IV, VIII). In addition, not all the interactive 3D elements need to have an effect, as there can also be hidden 3D objects and items for users to discover (IV). However, these should not be important navigational objects, but instead entertaining or rewarding features, such as games, or coupons to real stores (IV).



Fig. 8. An animated pulsating glow effect on an interactive object, e.g., rings in the center of the images, within a 3D VE. The size of the effect varies from 0 to 4 pixels within a 5-second timeframe.

Visual indication is also needed when moving 3D objects in a private 3D VE to show possible target objects (VIII) (Fig. 9, a). It is also necessary to show users' (II) or objects' active position between a private 3D UI and a public 3D VE (II,

VII). When moving objects, again a distinguishable glow was preferred (VII, VIII) (Fig. 9, b). The effect should be used as an outline of the shared object's and the target object's mesh (VII), as shown in Fig. 9, b. A dimming effect, e.g., darkening the background, could also be used to extract the non-interactive content while sharing (VIII) and to show users' active position between private and public 3D VEs (II).

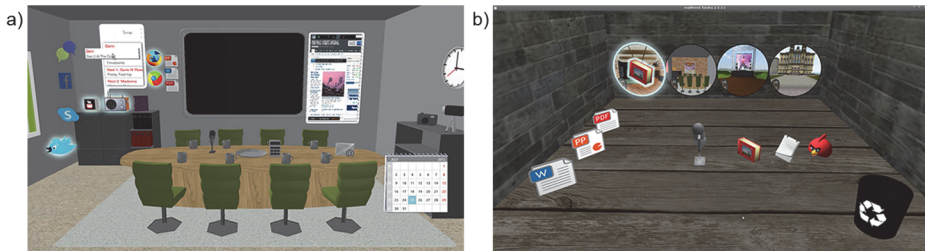


Fig. 9. Visual indication while moving items a) within a 3D VE and b) from a private 3D UI to a public 3D VE.

Interactive elements in tangible UIs should indicate the interaction they provide by objects' visual design (III). In particular, input and output objects should look different from each other (III) and not as presented in Fig. 10, a, where both input and output objects (pipets) appear identical. Furthermore, these interactive objects and elements in the UIs should not be physically aggressive, e.g., they should not transform or move under their own control (III) (Fig. 10, b). For example, the bracelet design presented in Fig. 10, b was perceived to behave aggressively, as its blades (small sections in the bracelet) independently curled when messages arrived.

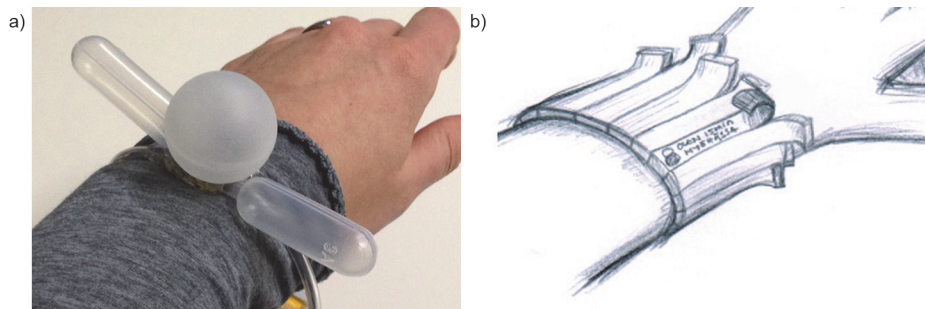


Fig. 10. Identical input and output objects in the prototype (a) and the bracelet concept were interpreted as aggressive due their independently curling interactive parts (b).

4.2.2 Impact of the context on an object's visual design

The context in which the interactive objects are used impacts how they should be presented. 2D icons seemed to pop up more easily from the 3D scene (IV), whereas 3D icons were more easily interpreted as part of the scene (IV). Even so, 2D icons should not be used to indicate all the interactive elements, as they depend on the content that they are presenting. 2D icons are suitable solutions for indicating 2D information, such as text and pictures (IV). Instead, 3D icons and elements should be used to indicate 3D content, such as 3D virtual activities or viewpoints, e.g., moving in the VE (IV).

Interactive objects in both in 2D and 3D UIs should be visually designed to be distinguished from their background context (II, V, VI). However, they should not occlude the view of the background space (II, V). Moreover, if the interactive element is representing a real item that exists in reality, such as a virtual house representing a certain house in a certain city, its color should not be changed while indicating its interactivity (IV).

If an interactive object is used to indicate location of an object or a person, then it should show the exact position (IV, V). In mobile social media applications, a user's location should be presented with a point or a pin (V) indicator. In 3D VEs, 2D icons are not a good choice for indicating elements' locations, as their actual location and relation to 3D elements in 3D space can be difficult to see (IV). Instead, 3D elements are better choices, as they are more natural looking in the 3D context (VI, IV).

In wearable tangible UIs, the use context sets limitations for the physical design of a UI. The UI should not cling to users' clothes while interacting with the device (III). The visual design of a wearable UI should take into account different use situations and the change of clothing accordingly, e.g., it should work for both leisure and business wear (III). The design of the UI and interactive objects in it should fit visually and functionally with other wrist devices and jewelry (III). Thus, the design of the UI and interactive objects in it should be petite and simple (III). The interaction with the wearable UI should be as unnoticeable as possible, as the interaction can take place in different public contexts (III).

5 Discussion

This thesis had two goals. The first was to determine how AUXs and users' needs and wishes for visual user interface design can be studied in the early development phase. The second was to provide design suggestions for the very detailed UI design issues. The thesis is a combination of eight publications describing seven UX studies. A total of 324 subjects participated in the studies. Six of the studies were conducted in the concept or early development phase, and one study was conducted both in the pre-launch and after launch phases. This study was included in the thesis as a comparison study. The comparison study provided more holistic understanding of UXs with fully functional product. All the other studies investigated AUXs with visual UI design. Most of the studies were conducted in laboratory settings, and only one study was implemented as an online survey. A combination of three different design approaches were chosen for this thesis: research-oriented design (Fallman 2003), RtD (Zimmerman *et al.* 2007), and constructive design research (Koskinen *et al.* 2011). The main data collection and analysis methods were qualitative, which were supplemented with quantitative methods in five studies. Publication V describes the initial version of the method developed to create ViDEs and evaluate them in the AUX studies. Publications II, III, IV, VI, VII, and VIII focus on visual UI design issues with mobile touchscreen, 3D, or wearable UIs. In parallel to studying these detailed UI design issues, the studies provided information on the created method's suitability for different design and evaluation cases. Thus, publication I draws all this information together and presents the finalized version of the created method, EDE. Publication I also describes how the method should be used to create comparable and consistent evaluation examples and to help in planning their AUX evaluations.

5.1 Theoretical and practical implications of the results

The thesis makes contributions to AUX research and UI design. First, in sub-sections 5.1.1, 5.1.2, 5.1.3, and 5.1.4, the EDE method's features are discussed. Then, in sub-section 5.1.5, the contributions related to the second research question and its sub-questions are discussed.

5.1.1 The EDE method allows AUXs and users' needs and wishes for UI design to be studied

The main contribution of this thesis is the findings related to the first main research question: *How can anticipated user experiences and users' needs and wishes for visual UI design be studied in the early development phase?* The findings support prior research (von Hippel 1986, Goodman *et al.* 2012) that AUX evaluations should not be conducted in a way in which subjects are forced to imagine their experience with future technology without giving concrete examples to which they can refer. Instead, AUX evaluations should always utilize proposed concepts created by a skilled professional designer who has sufficient knowledge about the topic to be able to create examples for the studies. Prior research has also acknowledged the need for methods and techniques that guide researchers on how to use concept representations in dialogue with subjects (Ozcelik Buskermolen *et al.* 2015) in early phase UX evaluations (Väänänen-Vainio-Mattila *et al.* 2008, Väänänen-Vainio-Mattila & Wäljäs 2009, Vermeeren *et al.* 2010, Bargas-Avila & Hornbæk 2011, 2012). To be able to design understandable and comparable examples that can generate data for the design process in AUX studies, the main contribution of this thesis is the practical three-step EDE method. The method provides guidance on how to create visual design examples and evaluate them in the early development phase AUX studies. The method enables AUXs and users' needs and wishes for visual UI, product, and service design to be collected. The EDE method was a good fit for the concept and early design and development phase UX studies, and it can be used to explore different concepts and/or to select the best choice among several ideas. It can be also used to create single examples for extending the functional prototype in situations in which the functional prototype is limited for its interaction or visual design.

5.1.2 The EDE method gives us a means for designing for interactivity

The basic principles of the EDE method are quite similar to those found in other human-centered design processes (Cox & Walker 1993, Kelley 2001, ISO 9241-210 2010, Rogers *et al.* 2011). However, the novelty is that in the EDE method, techniques are systematically combined with guidance and phasing of the process. The EDE method is also suitable for studying detailed as well as larger visual design issues in anticipated UX evaluation. Cox and Walker's (1993) model is

problem-centered; thus, the aim is to find a solution for a certain UI design problem. The EDE method is instead meant for exploring the design space and collecting users' needs and wishes for the design, not only for the problem indicated by the researcher. In addition, most of these models (Kelley 2001, ISO 9241-210 2010, Rogers *et al.* 2011) require understanding and specifying the use context and user requirements thoroughly before the design alternatives can be created, which can be quite time-consuming and difficult in some projects and design cases. The whole duration of these processes can last from one to even 10 years (Cox & Walker 1993, Ulrich & Eppinger 2012). Therefore, they are not ideal for smaller early phase AUX study purposes in fast-paced iterative projects. The length of one EDE method cycle depends highly on the design case and its breadth as well as the number of participants and examples in the study. In the study cases in this thesis, one EDE method cycle varied between a few weeks to a maximum of six months. In study 3 (II) the design case was quite large, with four different UI designs with detailed use cases; thus, it took months to design and create examples, evaluate them, and analyze the qualitative results of 40 participants. In contrary, in studies 4 and 5, the EDE cycle was substantially faster, and it did not take more than a couple of weeks to design, create, evaluate, and analyze the results. Thus, compared to larger human-centered processes, EDE was perceived to be faster.

The EDE method is not meant to compete with such processes, but it can be used as a parallel tool or sub-activity for gaining AUX-based knowledge for the design of product. For example, in Fig. 11, the author has illustrated how the EDE method can be used as a sub-activity/tool in different phases of the quite well known five-step human-centered design process developed by IDEO (Kelley 2001). The IDEO's five-step method is explained in detail in section 2.3.2. Kelley (2001) gives only textual description of the five-step method, thus visualization in Fig.11 author's vision of it. This method was chosen as an example because it is quite simple, yet valid and straightforward representation of human-centered design activity. In parallel with larger five-step design process, the EDE method can be used for understanding users and collecting their perceptions of the currently existing products visual design (Fig.11, 1). In addition, it can be used for generating different more detailed parts of the larger concept ideas and evaluating them in parallel with iterative prototyping, evaluation, and refinement steps (Fig.11, 2). Third, the EDE method can be used for collecting more detailed requirements after the concept design is implemented for commercialization, because it is really rare that products are not changed after they have been implemented (Fig.11, 3).

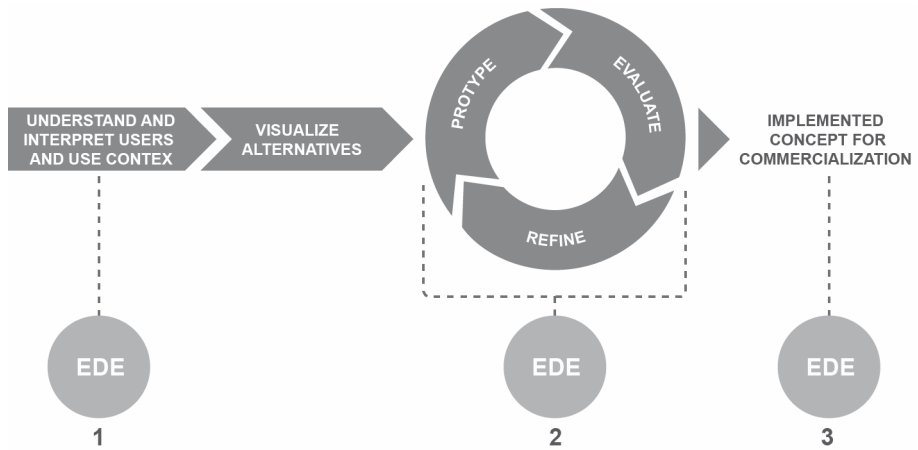


Fig. 11. Author's illustration of how the EDE method can be used as a parallel tool with the five-step method by IDEO (Kelley 2001). Visualization of IDEO's process is based on author's own vision of it.

When compared to other early phase UX evaluation methods (Gegner & Runonen 2012, Schütte 2006, Lavrakas 2008, Goodman *et al.* 2012), the main difference is that the EDE method explains how examples can be created for the studies. It also enables visual representations of the concept designs to be used, which are consistent and comparable to one another in AUX evaluations, which is not possible, for example, in Gegner and Runonen's (2012) AXE method. The EDE method also allows more than two designs to be compared, unlike paired comparison in which only two examples can be compared simultaneously (Lavrakas 2008). In addition, the EDE method does not require any special knowledge in the areas of engineering, statistics, and psychology, which all are necessary in KESo (Schütte 2006). Still, the EDE method is not for just anyone, as it requires expertise in visual design and UX research. In particular, design knowledge and an understanding of the design space and its possibilities are needed so that the designer can create suitable, understandable, and consistent examples. These examples should indicate future possibilities in a reliable manner, e.g., the presentation technique should be suitable for presenting a concept. The designer also needs to understand what is feasible in terms of technology to be able to create examples. For example, if the designer creates concepts that present some old technology or visualization techniques look dated, then they are not suitable for investigating future technology. Thus, as Roto *et al.* (2009) pointed out, designers

should use their expertise and trained skills to create examples that represent ideas that do not exist yet.

5.1.3 The EDE method allows for a mix of concrete examples plus conjecture about the future

The ViDEs can range from sketches to tidy computer-generated illustrations. The sketches were found to be suitable for studying less detailed concepts, such as product form, interior design, or anticipated interaction with a physical product. The findings of this thesis support Ozcelik Buskermolen *et al.* (2015) results that people who are exposed to sketchy representations tend to give more elaborated feedback and improvement suggestions with clear reasoning. In addition, as suggested by Ozcelik Buskermolen *et al.* (2015), in an interior design context, subjects' experiences were based on their prior real-life experiences. However, based on the findings of this thesis, sketches were not suitable for studying detailed UI design aspects, as they would be too laborious to draw in detail and drawings can be too inconsistent and unique in appearance to effectively compare the examples. Therefore, the findings of this thesis suggest that tidy computer-generated example images should be relied upon when studying UI design in the early development phase to be able to gain the most reliable results possible. This finding supports Kuutti *et al.* (2001) finding that the quality of the virtual prototype should be sufficiently high to prevent confusion. However, the findings of this thesis conflict with Gegner and Runonen's (2012) suggestion to use simple visual representations in AUX studies. Also contradicting the earlier literature (Löwgren & Stolterman, 2007), these findings suggest that tidy computer-generated expressions are not being interpreted as the final solution if their presentation form, e.g., paper or static images on a target device show that they are not even close to the final product. Moreover, the findings also are in contrast to van der Lelie's (2006) statement that computer-generated examples are easily interpreted *as is* and not being questioned much. As in the studies of this thesis, people were able to comment on and highlight negative aspects of the designs and present their needs and wishes, at least for the 3D GUI design. This finding supports Ozcelik Buskermolen *et al.* (2013) results that visually refined representations are more helpful when the aim is to elicit definite judgments of the concept idea rather than feedback grounded on subjects' prior experiences.

The number of examples used in AUX studies is highly dependent on the studied case and cannot be generalized. The example images should be designed as

comparable as possible when more than one example image is used. Therefore, it is important to use a uniform color theme, presentation technique, size, and style. The findings suggest that a single designer needs to create all the examples to ensure that the presentation technique and personal style do not affect the evaluation results.

5.1.4 The EDE method allows guided interaction with study participants

Prior researchers have acknowledged the challenges inherent in AUX studies, particularly if only textual scenarios or non-functional demonstrations are used to describe future technologies and concepts, as the design of future technologies might be difficult for participants to imagine (Olsson 2014). This is problematic, as von Hippel (1986) noted, when people are asked to imagine future, but they cannot generate any new ideas that conflict with the present technology they possess. The research results of this thesis support prior findings of Von Hippel (1986), Goodman *et al.* (2012), and Gegner and Runonen (2012) and is indicating the importance of using visual stimuli to prevent people just anticipating existing technology. Diederiks and Hoonhout (2007) also noted that rather than asking users what they want, scenarios combining textual explanations and images of concepts are more tangible and provide more concrete feedback for the design. The findings of this thesis suggest that visual design examples should be used in early development phase AUX studies, as they permit the design to be seen and anticipated before the finalized artifact exists. Another benefit of the ViDEs is that they offer a shared reference point for subjects and researchers, which supports prior findings by Godmann *et al.* (2012) and Gegner and Runonen (2012). They also enable diverse feedback to be collected, but at the same time, they are inflexible enough that the findings can be easily utilized in the finalized design. Thus, the findings of this thesis answer to the requirements suggested by Roto *et al.* (2011) and Law *et al.* (2009).

Prior research has highlighted the importance of functionality and usability (Hassenzahl & Tractinsky 2006) as well as the visual quality (Tractinsky 2013) of a prototype as important factors impacting UXs with the prototype, as experiences can be enduring. The results of this thesis support these findings and emphasize that visual design examples were also more effective than functional prototypes in studying AUXs of the visual UI design, as their visual quality was much better. Furthermore, another benefit of the ViDE images was that they permitted

participants to solely focus on evaluating the visual design. They also allowed users to envision the final design and see beyond the bulkiness of the functional prototype and thus evaluate the pleasurable nature of the whole concept idea. Arhipainen (2009) has acknowledged that novice users might assume that interactions with functional prototypes will be difficult, which may lead to nervousness and errors when interacting with them. The findings of this thesis complement earlier research by emphasizing that users can give more precise feedback on the design with ViDEs, as they feel more relaxed and are able to fully concentrate on the feature under evaluation.

5.1.5 Objects can indicate their interactivity by their appearance

The second contribution of this thesis is the findings regarding the second main research question: *How should interactive objects of studied UIs, both virtual and physical, be visually designed to be able to draw users' attention to them?* The findings suggest that the design of an object can indicate its interactivity. Users' attention can be drawn to an object by its shape, color, and its animated features, as these make an object stand out from its background space and other objects. First, the results for the visual indication within the 3D VE context are discussed and then the results for wearable deformable UIs.

Visual indication in a 3D VE context

The visual indication of interactive content within 3D VEs has not been researched extensively in collaborative VE research (Beeharee *et al.* 2003). Prior research has focused more on games (El-Nasr & Rao 2004, El-Nasr & Yan 2006, Milam *et al.* 2012). The problem with these studies is that games are more task-focused, user performance-directed, and visually more cluttered than CVEs and VEs, meant, for example, for social interaction or marketing travel locations in realistic-looking environments. The technical development in the area of 3D UIs has impacted the research. In particular, current graphical processing units (GPUs) can run heavier meshes and retina displays can show more detailed graphics than ever before; thus, the prior research and design suggestions developed based on earlier available technologies (Beeharee *et al.* 2003) might no longer be directly applicable. Therefore, the findings of this thesis can provide important preliminary suggestions on how the indication of interaction can be enhanced with visual cues within 3D VE. Prior findings support color as a pre-attentive feature (Green & Andersson

1956, Smith 1962, Carter 1982, Bundesen & Pedersen 1983). Object orientation and highly contrasting color have also been reported to enhance visual attention (Beeharee *et al.* 2003). The findings of this thesis are contradictory to these results, as in realistic-looking VEs a color overlay on an interactive object makes it look different than in reality, and thus it is difficult to recognize it. For example, if a yellow building is overlaid with blue color, the color of the house will look green; thus, it no longer appears the same as in reality. Therefore, in contrast to prior research by Beeharee *et al.* (2003), this thesis suggests highlighting interactive objects within the previously mentioned 3D VEs with a pulsating glow effect outline on objects' mesh. Study participants commented that the pulsating glow indication meant that an object had clear interactivity. This finding complements Milam *et al.* (2012) finding that a static visual cue will not stand out enough to be noticed in a scene. The finding in this thesis of highlighting interactive objects within 3D VEs with a pulsating glow effect outline on objects' mesh utilizes both bottom-up (the glow is a part of the environment) and top-down (the glow relates to human action) components. Therefore, this is complementing prior research done by Beeharee *et al.* (2003), who suggested using both bottom-up and top-down components for gaining visual attention in densely populated, behaviorally rich, and highly interactive distributed VEs.

Prior research by El-Nasr and Yan (2006) highlighted that novice users of 3D VEs might not notice important items or can get lost. The findings of this thesis complement their research by emphasizing that visual indication is important, particularly for novice users, so that they can find interactive content within the 3D VEs. The pulsating glow effect should be used when a user enters the VE and also when interacting with the objects in it. The indication does not have to be shown all the time, but it can end automatically, or a user can switch it off when needed. In addition, when sharing objects from private UIs to public spaces, the visual indication should be used and shown on both shared and target objects' mesh. Extracting the non-interactive content while sharing items or showing users' active position between private and public 3D VEs can be done with the dimming effect, e.g., darkening the background.

Visual indication of interactivity in tangible wearable deformable UIs

The visual design of tangible wearable deformable technology has not been dealt with extensively in prior literature, as it has focused mostly on technical development (Rasmussen *et al.* 2012). It is suggested that future research should

collect user reactions to these interfaces, how these UIs could be used, and in what contexts (Rasmussen *et al.* 2012). This thesis answers this call and offers early AUX-based suggestions for the research community for the visual design of wearable and deformable UIs and impact of the use context on the design. The findings of this thesis are also more refined than the early concept ideas presented in prior research (Ahde & Mikkonen 2008, Fortman 2013), as the concepts in this thesis were studied in two AUX studies, and in the second, a functional prototype was utilized as well. The finding of this thesis suggests that interactive objects' visual design in wearable tangible UIs should indicate the offering of the possible interaction. Thus, input and output objects should differ in their visual design. The use context also sets limitations for the visual design of wearable technology and interactive objects in it. Interactive objects should be able to be manipulated, regardless of the type of clothing a user is wearing, e.g., objects should not cling to them during the interaction. The visual design of a wearable device and interactive objects in it should accommodate to different use situations and clothes used in them, both in business and leisure. The UI should allow unnoticeable interaction in different public contexts. These findings complement Miner *et al.* (2001) assertion that the less interfering a device is, the easier it is to fully integrate into one's daily life. The findings of this thesis also suggest that the visual design of a UI and interactive objects in it should be petite and fit visually, aesthetically, and functionally with users' clothing, other wrist-worn devices, and jewelry/bracelets. This complements prior research by McCarthy (2006), who suggested that the aesthetic design of a device significantly impacts users' willingness to wear and use the device. In addition, the thesis findings suggest that wearable technology should not have an aggressive appearance or behavior.

5.2 Limitations of the studies

One challenge with the studies conducted during this thesis is that many of them (V, VI, VII, VIII) were focused on very detailed visual UI design issues. Thus, the smaller studies conducted to test the EDE method's suitability and publications written on them do not offer information on the method and reflections on its use. Most of the reflection on and interpretation of the process of using the method was done while writing publication I. Nonetheless, the method has been tested in different study cases at least once and compared to one study conducted without it. Based on the experiences of the EDE method and the ViDEs in AUX studies, the method appears to be suitable for AUX studies. One limitation of the EDE method

was that it was not possible to interaction and animation features with static images. However, the findings involving the paper examples created using the EDE method (VII, VIII) were confirmed in another study conducted with a launched product (IV), which adds to the credibility of the ViDEs' ability to deliver AUX information. However, more studies need to be conducted to be able to make generalizable statements on how accurate the predictions done in the anticipated use situation can be in an actual use situation. Also, if only singular small studies with a very detailed focus are conducted, they will not be able to provide holistic understanding of AUX. Thus, in these kinds of cases, the design has to be iterative, starting with more holistic topics and progressing toward more specific design cases, as Buxton (2007) pointed out that studies should first focus on selecting the right design for the development and then later studies should focus on validating the design solutions. In addition, although the EDE method was tested in different design cases, it was not systematically compared to other processes and models to evaluate its strengths, limitations, and applicability in different design cases.

5.2.1 Evaluation materials and subjects

The evaluation materials and subjects in the studies have an impact on the reliability of the results in AUX evaluation. The sample of users was chosen based on their availability; thus, it is likely that the best possible future user representatives did not participate. The recruitment of participants depends on the costs and the time available. Therefore, it is hardly ever possible to get a homogeneous group of people to participate in a study who all represent the target user group. Furthermore, in most of the studies, the sample was not limited to only people who had experience with the technology, but instead it was preferable to include novice users.

Prior researchers (Olsson 2012, von Hippel 1986, Goodman *et al.* 2012) have reported another problem with AUX studies: subjects' needs and wishes might be based on their prior experiences with the technology or related technology. This is quite problematic in AUX evaluations; thus, the author tried to prevent this by providing ViDEs created through the EDE method. The author believes that this made the results more reliable. It is also easy to blame subjects, but researchers should question the examples and their understandability for the subjects. Prior research suggests giving concrete examples, allowing subjects to merely comment and give feedback rather than forcing them to create ideas, which is not natural for them (Goodman *et al.* 2012). The visual examples used in the present studies were

created to be as consistent and comparable as possible to avoid bias. In addition, the created examples showed the possibilities of the technology in a trustworthy manner, as their visual and interaction design possibilities were in line with the current technology. All the examples were created by one designer, and if another designer helped, then the author was responsible for constructing the final examples to ensure that the examples were comparable and consistent.

The selected research approach, a combination of research-oriented design (Fallman 2003), RtD (Zimmerman *et al.* 2007), and constructive design research (Koskinen *et al.* 2011) worked well, for the following reasons. First, the approach was beneficial in that it did not limit what kinds of artifact could be used in the studies. Thus, the examples used in the studies ranged from sketches to fully functional prototypes. Second, its requirement for the novelty of the contribution was much more flexible than, for example, in the RtD approach. This also permitted the creation of incremental evaluation examples for cases in which the focus was on exploring user preferences for certain application areas, such as in the first study with location indicators (V). In design research, it should be possible to freely explore different possibilities without having to consider whether the contribution is really novel. It is quite common for people to design similar things or import ideas from other fields or contexts and only rarely can something truly novel be invented. Thus, it seems odd that good ideas might not be valuable contributions if they are seen only as incremental contributions. In addition, in some small cases, we need to use incremental design to be able change applications to provide better UXs.

5.2.2 Limitations of the user interface design findings

The findings for the UI design in this thesis cannot be generalized, as they are meant for specific objects in specific application contexts and UIs. They also deal with very specific user interface issues and thus cannot be solely used for guiding design toward more pleasurable UIs. Another major limitation is that most of the findings are still preliminary and require further research. The results can help to improve UXs with the studied UIs. However, they are the first steps toward providing a good user experience for the users of the UIs and further research is needed to be able to improve UX holistically.

According to Jumisko-Pyykkö (2011), in top-down processing, humans' prior knowledge in the forms of expectations, attitudes, emotions, and goal-oriented action toward perceptions affect how things are perceived. In the studies, some of

the participants had prior experiences with 3D games, in which a pulsating glow effect is used quite often to indicate something that needs to be noticed. A similar effect has also been used in some 2D web pages to indicate important items. Thus, their understanding of the meaning of the effect can come from such contexts.

5.2.3 Reliability of the data collection and analysis methods

Over 50% of prior UX studies collected data through questionnaires and only 20% with semi-structured interviews (Bargas-Avila & Hornbæk 2012). When trying to understand AUX using only quantitative methods, important subjective insights might be missed, as they are not significant enough. As Hart *et al.* (2013) stated, the qualitative analysis of deep reflective interviews was able to reveal differences in overall experiences, which was not possible with the quantitative analysis of numerical data. Moreover, a questionnaire is not a direct way to capture users' feelings and needs, as it is normally used after completing a task or an entire study when the experiences are not as strong and might have already been forgotten. Further, questionnaires rely on predefined questions and defining questions cannot be asked later, which might lead to a knowledge gap or even inaccurate interpretations of users' comments. On the other hand, in a semi-structured interview, it is possible to elaborate on what users stated, and thus a more comprehensive understanding of UXs is gained. As Hart *et al.* (2013) reported, quantitative survey responses could be based on memory, while an interview can motivate deeper reflection and is therefore able to reveal more detailed and refined information of a topic. The findings of this thesis support prior research knowledge (Arhippainen 2009, Goodman *et al.* 2012, Hart *et al.* 2013) and highlight the importance of semi-structured interviews and qualitative data analysis in UX research. Many times throughout the studies, one subject made an important comment that offered a new possible direction for the design that could not have been elicited by quantitative methods. Therefore, the selected qualitative data collection methods, interview and observation, were found to be suitable for AUX evaluations.

The EDE method allowed mixed methods (Creswell & Plano-Clark 2011) studies to be conducted. The emphasis was on qualitative data, e.g. qualitative priority, which was perceived to be the best approach for understanding AUXs and users' needs and wishes for the design. Quantitative data collection methods were perceived to work well, particularly when highlighting the best choices from given

examples. In addition, semantic word pair scales complemented the qualitative data well.

Qualitative analysis, and general qualitative coding (Charmaz 2005) in particular, was found to work well when analyzing the results, as it enabled subjective user comments to be emphasized as well as matters indicated by many subjects. Thus, it allowed to form the richest possible image of user needs and wishes for the UI design. However, the reliability of the findings can always be questioned. It is difficult to objectively analyze the data, as researchers' own interests will lead the analysis. In addition, the author was coding qualitative data alone in most of the studies 1, 2, 4–7 (III, IV, V, VI, VII, VIII), and thus it was not possible to determine the inter-coder reliability. When analyzing data from study 3 (II) and for publication I, coding was assisted by another researcher. The analysis of drawings by applying the affinity diagram method was done together with another researcher, and thus the analysis of these studies' (3 & 7/ E2, II & III) data is more reliable.

Even though author was not in charge of analyzing quantitative data, there are a few matters that can be questioned. The quantitative analysis of the significance between all the variables was difficult because of the large number of examples. In studies 1 and 5, the number of examples ranged from 7 to 14; thus, the analysis was performed between the three highest-scoring options. In study 7/E1, due to a large number of combinations, it was not feasible to test the significance of measured differences between all the concept designs, and thus only the best and worse were tested.

The EDE method also allowed methodological triangulation because visual examples were easy to combine with other prototypes and data collection methods, such as self-expression templates. The self-expression task was the final task in studies 3 (II) and 7/ E2 (III), which enabled subjects to digest all the designs they had seen during the evaluation and then draw their design using the best features as a source of inspiration. The templates worked well in the early concept phase evaluation study 3 (II), as no functional prototypes were used. One general problem with the template task was that people tended to draw or write items that they knew or had seen in other products. If self-reporting methods are used, the evaluation needs to be carefully planned to prevent participants from basing their experiences, as warned by von Hippel (1986) and Goodman *et al.* (2012), on their real-life experiences. Thus, based on the experiences gained from two studies, the template task should be the last task, as it is better to increase participants' knowledge by showing different design alternatives as a base for new ideas; as such, the results

can be more reliable. This worked well in study 3 (II), as participants were able to combine the best-perceived features of the concepts in the drawing. However, although it was the final task in the evaluation in study 7/ E2 (III), the drawing template was not able to extract many new ideas. This was likely not merely due to the method, but the topic and the development phase might have also impacted subjects' drawing, as most were not able to come up with new ideas.

5.3 Future research opportunities

The preliminary suggestions for indicating the interactivity of an object presented in this thesis provide a starting point for further research. These suggestions show that the visual indication of interactive elements is an interesting research area and deserves further in-depth research. As the focus of the studies was on UX, there was no opportunity to study the affordance of the objects or human perception in more detail. For example, it could be beneficial to investigate whether the glowing effect could act as an affordance for an object. In addition, it would be investigated in which other UI contexts visual indication could be used. One possible application and technology area could be augmented reality applications for the maintenance of factories or power plants to indicate possible dangers or risks. Moreover, most prior researchers have not explored how subjects perceive objects' interactiveness, particularly in the field of tangible wearable and deformable UIs. More research is also needed on the visual design of tangible wearable and deformable UIs. In addition, as new interesting interaction capabilities are invented, this research area keeps evolving. Thus, there is a need for further qualitative research in the area of the visualization of objects and the visual design of 2D mobile touchscreen, 3D, and wearable UIs.

Anticipated user experience requires an agreed-upon definition so that the phenomenon can be better understood. The definition should show how AUXs and users' needs and wishes regarding the new concepts of technology, services, and products can and should be studied.

Last but not least, the EDE method needs to be extensively tested by other researchers to determine how it works in other design cases. In addition, as most of the current graphical services, applications, and UIs use many animations, the EDE method could be used to create animated examples and use them as stimuli in AUX studies. It would also be beneficial to investigate the presentation form of the visual design examples and its impact on AUXs. Although the EDE method was developed for early phase studies, it could also be useful in later development phase

UX studies, particularly because it is perceived to be lightweight, and thus it could be used in parallel, as an extra tool for charting user needs for detailed visual design aspects, such as the icon design of a product in late phases of development. The EDE method could also be useful in studies done with launched products, as there is always something that needs to be improved after the launch. In addition, the EDE method should be systematically evaluated against other methods and processes to assess its duration, strengths, limitations, and applicability in different design cases. For possible suggestions regarding how the systematic comparison could be done, refer to Strohmeier (2011) and Özçelik-Buskermolen (2013).

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