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User Expectations and Experiences of Mobile Augmented Reality Services

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User Expectations and Experiences of Mobile Augmented Reality Services

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Abstract

Mobile Augmented Reality (MAR) as an emerging field of technology has the potential to engender services that demonstrate novel aspects like enriching the reality with digital information, location-based interaction, and tangible user interfaces. The early visions of MAR anticipated it to revolutionize the way of accessing and interacting with information in mobile contexts. However, one hindrance in this path is the lack of research understanding of the subjective *user experience* (UX) resulting from, e.g., the novel interaction metaphors and the mixing of realities that MAR embodies. What is more, little is known about users' *expectations* of the futuristic concept of MAR and the experiences it could evoke. Because of the increasing importance of UX as a quality attribute in products and services, there is a need to understand the characteristics and expectations of UX in specific emerging fields like MAR.

The goal of this thesis research is twofold: (1) to understand potential users' *expectations* with regard to UX of future MAR services and (2) to understand the *actual UX* of the recent first-generation MAR applications like Junaio and Layar. By understanding the scope of expectations and experience that can take place in the field of MAR, it is possible to help the design and engineering of AR-based services to consider also the experiential aspirations of potential end users.

This compound thesis belongs to the research field of Human-Computer Interaction. It contains four studies, in which altogether 401 persons participated in either interviews or online surveys. The empirical findings on expected and actual experiences are reported in six publications. The theoretical contribution is mostly conceptual, culminating to a framework that describes the facets of UX and categories of meaningful experiences in MAR. Based on the empirical findings and the framework, the practical contribution is concretized in the form of (1) design implications and (2) subjective evaluation measures to help designing future MAR services with an experience-oriented approach.

According to the results, potential users (early adopters) expected MAR services to create a great extent of pleasurable experiences, such as empowerment, surprise, awareness, liveliness, playfulness, tangibility, collectivity, inspiration and creativity. Furthermore, the expectations were attributed to a variety of service components, also relating to other ubiquitous computing aspects (e.g., the augmentation as an output, proactive functionalities, and embedding of digital content to the reality). This implies that emerging technological concepts like MAR are perceived in very diverse ways and that people's expectations of them consist largely of general needs and desires.

The existing first-generation MAR applications, however, seem generally not to fulfill the expectations, showing a much narrower extent of actualized experience characteristics. This experiential gap, as well as the narrower extent of functionalities in current applications, contains much potential with regard to pursuing a rich and pleasurable UX in future design of MAR services.

The empirical results, conceptualizations and practical implications can be utilized and built on in academic research as well as in development of MAR. The novelty and complexity of both MAR and UX as concepts elicit an extensive breadth of aspects to be studied in detail in future research and development – regarding both MAR as a field of technology and UX as a field of theory.

Preface

This research journey started in fall 2008 as a part of the DIEM/MMR project – albeit it was only in late 2010 when I recognized it as one that could actually result in a doctoral dissertation – and culminates in this piece of literature I am so fondly proud of. Looking back at this journey, I feel privileged for the support and possibilities I was given by so many people.

First and foremost, I am grateful to my supervisor Prof. Kaisa Väänänen-Vainio-Mattila for her inspiring support and the practice of optimal guiding: giving space to explore what I please and get motivated by but, at the same time, giving subtle pushes towards the path that most probably leads also to a dissertation. I want to thank the pre-examiners of the thesis, Mark Billinghurst and Mark Blythe, for very detailed examination and the insightful and constructive comments in the finalization phase of the thesis. I am honoured to have Associate Professor Thomas Pederson and Docent Jonna Häkkilä agreed to act as the opponents in the public defense.

I owe a lot to my co-authors and colleagues. All of you deserve a great deal of my gratitude for helping out in conducting the research and making the best of the research results: Tuula Kärkkäinen, Else Lagerstam, Pirita Ihamäki, Markus Salo, Tuomas Vaittinen, Leena Ventä-Olkkonen, and Tomi Haustola. In addition, Minna Kynsilehto is not a co-author in any of the papers here but has been a truly inspirational colleague over the years. The context of the research, the Tekes-TIVIT project 'Devices and Interoperability EcosysteMs' (DIEM) / 'Mobile Mixed Reality' (MMR) – with all the researchers and colleagues involved – deserves to be acknowledged. I am grateful to the project for the opportunity to focus on my research topic for three years, as well as to Tekes for funding it. I want to thank especially Ville-Veikko Mattila, Charles Woodward, Timo Tossavainen, David Murphy, Niko Frilander, Esin Guldogan, Marketta Niemelä, Olli-Pekka Pohjola, and Sari Wallden for the opportunity of working with top-notch researchers and following the development of interesting enabling technologies for Augmented Reality from the best possible position.

When trying to figure out the big picture and refining the narration of the thesis, I received excellent comments from Sari Kujala, Teija Vainio, Minna Kynsilehto, Markus Salo and Heli Väätäjä. I owe you one. Fellows at IHTE, you are simply awesome, and perhaps the main reason I got carried away with research in the first place. In addition, I am happy to have been involved in the community of UCIT doctoral school and grateful for the travel funding to two conferences to present my papers. During these years, I received grants from Nokia Foundation and Elisa-HPY, which helped me to advance the research and especially to take the required time for finalizing the thesis.

The greatest gratitude belongs to my family: Jaana, our cats, Mom, Dad, Nikke & family, Linda. Thank you for the past and future years, for making this possible in so many ways, and for not questioning why on earth am I doing this. I can never express my love and gratitude enough.

Tampere, 7.10.2012 Thomas Olsson

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Contents

List of Publications

This thesis consists of an introductory part and six original publications. In addition to the reference information, the candidate's contributions to the publications and the studies behind them are explicated in the following. The publications are reproduced by permission of the publishers and they are referred in the thesis by Roman numerals **I-VI**.

I. Olsson T, Ihamäki P, Lagerstam E, Ventä-Olkkonen L, Väänänen-Vainio-Mattila K (2009) User expectations for mobile mixed reality services: an initial user study. Proceedings of the 4th European Conference for Cognitive Ergonomics, ECCE'09, Sep 9th - Oct. 2nd 2009, Otaniemi, Espoo. ACM Press, pp. 177-184.

Olsson led the planning of the study and carried out the data gathering and analysis together with his colleagues. He was the principal author and was in charge of producing the publication.

II. Olsson T, Lagerstam E, Kärkkäinen T, Väänänen-Vainio-Mattila K (2011) Expected user experience of mobile augmented reality services: a user study in the context of shopping centers. Journal of Personal and Ubiquitous Computing. Springer. DOI: 10.1007/s00779-011-0494-x

Olsson led the planning of the study and carried out the data gathering and analysis together with his colleagues. As for the publication, he was the principal author with a major contribution in both planning the paper and writing it.

III. Olsson T, Kärkkäinen T, Lagerstam E, Ventä-Olkkonen L (2012) User evaluation of mobile augmented reality scenarios. Journal of Ambient Intelligence and Smart Environments 4(1), thematic issue on Virtual and Mixed Reality Intelligent Environments. IOS Press, pp. 29-47.

Olsson led the planning of the study and carried out the data gathering as well as the qualitative and quantitative analysis together with his colleagues. As the principal author of the paper, his contribution was major.

IV. Olsson T and Salo M (2011) Online user survey on current mobile augmented reality applications. Proceedings of the 10th IEEE and ACM International Symposium on Mixed and Augmented Reality, ISMAR'11, Oct 25 – 29th, Basel, Switzerland. IEEE, pp. 75-84.

Olsson planned the study in collaboration with Salo, however being responsible of most of the parts of the survey that were reported in this paper. Most of the analysis was carried out by Olsson. As the principal author, he was responsible of planning the paper and had a major contribution in writing it.

V. Olsson T and Salo M (2012) Narratives of satisfying and unsatisfying experiences of current mobile augmented reality applications. Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems, CHI'12, May 5th – 10th, Austin, Texas, USA. ACM Press, pp. 2779-2788.

Olsson designed the parts of the survey that were reported in this paper. The analysis was carried out collaboratively but was coordinated by Olsson. With regard to the paper, he was the prime contributor of both planning and writing it.

VI. Olsson T (2012) Concepts and subjective measures for evaluating user experience of mobile AR services. Forthcoming in: Huang W, Alem L, Livingston M (eds.) Human Factors in Augmented Reality Environment. Springer, 295p.

Olsson was the sole author and carried out the cross-case analysis of the different studies by himself.

In this introductory part of the dissertation, most of the findings and contributions of the above-mentioned papers are summarized and presented in a slightly abstracted form. An exception to this is Paper **VI**. Its main contribution, that is, an extensive set of subjective evaluation statements for mobile augmented reality services, was not regarded as such that could be repeated merely for summarization reasons. Consequently, readers interested in this specific contribution are adviced to read the paper in its entirety.

List of Acronyms and Terms

3D	Three-dimensional. In augmented reality, relates especially to creating realistic augmentations that utilize three spatial dimensions instead of two
AmI	Ambient Intelligence. A user-centric vision of future where sensitive devices disappear in the background to support people (Remagnino & Foresti 2005)
AR	Augmented Reality. A mesh-technology and vision of technology that augments a view of the real world with virtual, computer-generated information that is interactive and in real time (Mackay 1996, Azuma 1997)
Computer vision	Computer-based processing to mimic the abilities of human vision by electronically perceiving images and their visual features (Sonka et al. 2008)
Content	Digital information that, in this thesis, is acquired with a MAR interface
Context	Context is any information that can be used to characterize the situation of an entity (Dey 2001): e.g. social, cultural, physical or task context
Context awareness	A system using context to provide relevant information or services to the user, where relevancy depends on the user's task (Dey 2001)
FOV	Field of view
Handheld	A mobile device that can be held and used in one hand
GPS	Global Positioning System. A generally used service for positioning
HCI	Human-Computer Interaction. A field of research focused on the interaction between humans and technology; often in relation to design and evaluation of computer based systems and products (ISO 2010)
LBS	Location-Based Service. Computer program-level services that utilize location information to provide the user with location-relevant information
MAR	Mobile Augmented Reality. AR created with mobile devices and for purposes that are common in mobile contexts
MR	Mixed Reality. A collective term for concepts about integration of the real and virtual realms (Milgram & Kishino 1994)
PDA	Personal Digital Assistant
POI	Point of Interest (e.g., an interactive information point on a map interface)
Service	In this thesis, an entity comprising of the functionalities enabled by the underlying technology (system), the way of interacting with the technology, and the information content being accessed and used with it
Ubicomp	Ubiquitous computing, a vision of future computing where devices blend in the environment and technology is available everywhere (Weiser 1991)
UCD	User-Centered Design
UI	User Interface. The entity through which a user uses and manipulates a system and the system indicates the effects of the user's manipulation
UX	User Experience. "A person's perceptions and responses that result from the use or anticipated use of a product, system or service" (ISO 2010)

1. Introduction

This chapter illuminates the fundamental premises of the thesis and describes various background phenomena that have instigated this research. The scope and overall approach of the thesis are described and positioned according to certain scientific disciplines and metatheories. Furthermore, the research questions and practical objectives of the thesis are presented, and the contributions addressing them summarized.

1.1 Crossing Mobile Augmented Reality with User Experience

Mobile technologies, such as mobile phones, tablet computers, wireless networks and mobile Internet, are becoming increasingly pervasive and universally adopted in various areas of people's lives. Mobile devices and services are utilized in day-to-day basis in professional activities, recreation activities, alone as well as in groups, and in all kinds of physical environments. It is evident that mobile industry is a huge driver of business and hence a fruitful area for product and service development.

Recent advancement of mobile technology is increasingly catalyzing the advent of Ubiquitous Computing (Ubicomp). York and Pendharhar (2004) propose a formal definition for Ubicomp: "machines that fit the human environment instead of forcing humans to enter theirs". However, the diversity of what the concept is understood to cover is extensive. Ubicomp involves aspects like technology services being available anywhere and anytime (Weiser 1991, Hansmann et al. 2003), minimal user distraction (Satyanarayanan 2001), integration of the strengths of both the real and digital worlds in a user single interface (Mackay 1996), and generally providing user interfaces that are efficient, effortless and intuitive for people.

Related to Ubicomp, two central ongoing developments form the basis of the field explored in this thesis. First, mobile devices are becoming increasingly *aware* of the information resources and services nearby, the current physical surroundings, as well as other characteristics of the user's context (Schmidt 2002, Oulasvirta 2004). With machine vision solutions and integrated sensors, such as cameras, microphones and orientation sensors, mobile devices not only have the capabilities to perceive aspects that are unobservable for humans (e.g., networks and digital resources), but also to 'see and hear' the surrounding world in similar ways as humans. Second, information content is becoming linked to perceivable everyday things like products, people and locations. This allows the things themselves to be used as sources and affordances – i.e., cues of possible actions – for digital information (Atzori et al. 2010, Norman 2002). A currently predominant manifestation of both of these developments is *Location-Based Services* (LBS), which aims to provide the users with mobile services based on the location of the user (Dey et al. 2010).

As both a consequence and a remarkable demonstrator of the above-mentioned developments, *Augmented Reality* (AR) has been a highly eye-catching technology over the last few years. According to a broad definition, AR combines real and computer-generated digital information into the user's view of the physical and interactive real world so that they appear as one environment (Azuma 1993,

Vallino 1998). Perhaps the earliest and most well known examples of augmented reality relate to science fiction, computer games and sports: the improved and computerized visions of the Terminator or Robocop movies' characters, the enhanced displays on driving or flying simulators with data about the environment and the vehicle, or in sports, superimposing a line that represents the current record. Figure 1 illustrates a present-day example of location-based digital information being augmented on the camera view of a mobile phone. Overall, augmented reality has been envisioned to revolutionize the way in which information is accessed and presented to people and thus enhance our daily activities (Wellner et al. 1993).

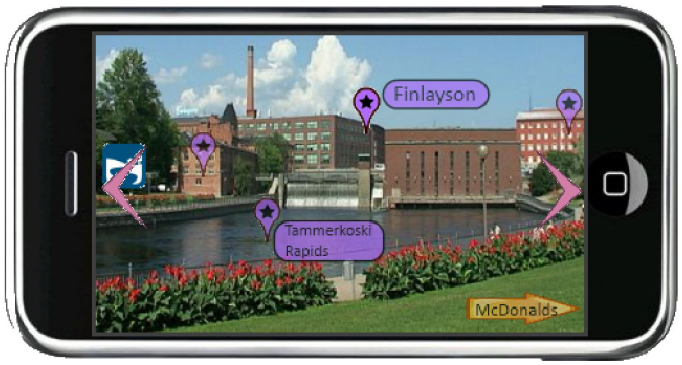

Figure 1. A concept image of a mobile AR view that superimposes POI information related to surrounding locations as well as simple guidance information on top of the device's camera view.

AR as a field of technology has been attributed with high expectations. According to Gartner's recent hype cycle (Gartner 2011), AR is on the peak of inflated expectations, meaning that mass media hype has begun and there is some activity beyond early adopters. In 2008, Gartner Research listed AR in the top ten disruptive information technologies for 2008 to 2012 (Gartner 2008). The technology review by MIT (Jonietz 2007) lists AR one of the "most likely to alter industries, field of research and the way we live". On the other hand, the number of people having adopted AR is still marginal, and mainstream adoption can be expected only after 5-10 years. Nevertheless, the technological premises for the breakthrough of AR already exist. It can be argued that technologies enabling AR have reached such a level of maturity that consumer-targeted commercial services with demonstration of true value to the user can be engendered.

Mobile Augmented Reality (MAR) refers to utilizing AR with mobile devices and for purposes that are common in mobile contexts. As the current mobile devices are becoming increasingly capable to compute and utilize aspects like computer vision and user positioning, mobility is perhaps the most potential way for augmented reality to become widespread. With the recent introductions of rather widely adopted mobile applications like Layar[1], Junaio[2], Wikitude[3] and Acrossair[4], we are witnessing AR technologies to become exploitable for purposes of, for example, browsing location-based content, navigation, gaming, and identifying products while mobile.

[1] www.layar.com
[2] www.junaio.com
[3] www.wikitude.org
[4] www.acrossair.com

MAR has been expected to create new businesses and activities around areas like acquisition of digital information related to places and objects, exploration and adventuring, navigation, advertizing, retail, and gaming (e.g. Wither et al. 2009). Pointing a camera-equipped mobile device towards an object and getting instant, context-sensitive information about it can revolutionize how we access, understand and enjoy digital information in the future mobile life. Naturally, this creates challenges for designing services that truly take advantage of what users perceive as the strengths and benefits of AR as an interface. Overall, little research knowledge exists about the user-related challenges in mobile AR (Dünser et al. 2008) – not to mention the user's *experience* of such a new technology.

Over the last decade, producing a pleasurable *User Experience* (UX) has become an increasingly influential quality attribute and a business-critical asset in design of technology products and services (Hassenzahl 2003). UX is regarded as a comprehensive concept describing the subjective experience resulting from the interaction with technology (ISO 2010). UX is generally agreed to depend on the person and contextual factors, and to be temporally evolving (Law et al. 2009). There has been a growing interest in understanding especially the ontology and characteristics of experience in use of technology. For example, elements of instrumental, emotional, sensory, social and aesthetic experiences are often identified (Buccini & Padovani 2007, Desmet & Hekkert 2007).

As a result of people's growing expectations regarding new technology and the ongoing societal development – the change towards 'experience economy' (Pine & Gilmore 1998) – it has become increasingly important to understand also the expectations that people have of technology and the services built around them. Users' expectations (also referred to as *anticipated UX*) and user experience are highly intercorrelating concepts, both affecting the other (Wright et al. 2008). User's expectations have been argued to reflect anticipated behavior, direct attention and interpretation (Hiltunen et al. 2002) and influence the user's perceptions of the product (Arhippainen 2009), thus having an influence on forming the actual user experience of the product (e.g., experience of the product's efficacy). In addition, as the standardized *User-Centered Design* (UCD) approach suggests, products and services should be based on true or latent needs, concerns and expectations of the potential end user group (ISO 1999). Studying people's expectations of the technology as an expression – or even prognostication – of the actual UX is a fruitful, yet exiguously explored area of research in HCI.

Considering that MAR is an exciting nascent technology with promise to offer a novel interface to contextual information in the constantly changing mobile environments, the user's experience of MAR services is challenging to predict or envision. Therefore, I argue that it can be insightful to understand what people expect of the experience, hence gaining new insight into what kind of experiential design targets, limitations, needs and other considerations apply to designing and evaluating mobile AR. In addition to exploring the potential users' expectations, it is also important to understand the UX of the existing first-generation MAR applications – partly also to reflect how the expectations have been met and to identify what further experiential potential the expectations can offer to the design of future services. Moreover, despite the plethora of recently published general-level frameworks of UX, there is a lack of UX research understanding and theoretical frameworks in specific fields of technology like mobile augmented reality (Law et al. 2009).

1.2 Research Scope and Approach

This research belongs to the multidisciplinary field of human-computer interaction (HCI). On one hand, this research represents engineering and computer science with their practical goals of furthering the development of technology. On the other hand, HCI research often focuses on humans and their reactions and behavior, and hence the research methods stem from behavioral and social sciences. Furthermore, the methodology is based on the principles of user-centered design (UCD). UCD is a design philosophy where the needs and requirements of end users are in focus at each stage of the design process (ISO 1999). Consequently, the ultimate motivation of the thesis is to facilitate optimizing augmented reality concepts to fit the needs and expectations of the potential users, thus helping people's lives with sensible technology services. Regarding the UCD principles in the ISO 9241-210 (ISO 2010), this thesis emphasizes (1) explicit understanding of users, their tasks and contexts of use, (2) driving and refining the design by user-centered evaluation, and (3) addressing the whole user experience. Additionally, the philosophy of science contains various dichotomies and positionings. Next, a few of such are discussed in order to further characterize this thesis.

First, this research is mostly *qualitative* by nature. Qualitative research aims to understand various phenomena and the reasons behind them (questions of 'why' and 'how'), whereas quantitative research aims to create generalizable models and theories with numeric methods, such as statistics and causalities (Alasuutari 1993, Silverman 2010). Although the research questions and most methods (e.g. contextual interviews, focus groups) represent qualitative research, the quantitative approach is utilized in specific analysis methods of online survey data. Therefore, the research can be said to utilize method *triangulation* and *mixed-methods* approach (Creswell & Plano Clark 2006) in order to holistically cover the studied phenomena.

Second, this research has an *inductive* reasoning approach rather than a deductive (Niiniluoto 2002): the research is grounded on empirical observations that are analysed to create theories that represent and explain the phenomena. Consequently, in analysis of experience as a phenomenon, principles from *grounded theory* approach are used together with thematic analysis. In practice, this means that existing UX theories guide identification of themes and categorization as little as possible. Hence, data gathering, analysis and theory are in reciprocal relationship with each other (Strauss & Corbin 1990).

Third, the epistemological stance tilts slightly towards *subjectivity* rather than objectivity: the truth and reality – and especially how they are experienced – depend on the subject. Especially the analysis of qualitative data can never be free of personal values and impressions.

Lastly, this research represents *instrumentalism* rather than verism: it has an instrumental value and aims to help people and the society, the economy and creation of innovations, and welfare in general (Niiniluoto 1997). The empirical results relate largely to concepts of user experience and expectations, which have foundations in cognition research, emotional psychology, sociology, anthropology, as well as marketing and consumer science. This human-centered understanding is transferred to design recommendations for the engineering fields and computer science. Hence, this research is, on one hand, *basic* research, i.e., developing theories and concepts, and, on the other hand, *applied* research, i.e., aiming to provide design and evaluation implications for AR technologies.

Regarding terminology, a central concept and viewpoint in the thesis is *MAR service*. Here, with a service is meant the entity comprising of (1) the functionalities enabled by the underlying technology, (2) the way of interacting with the technology, and (3) the information content being accessed and used with it. These represent the elements that are evident for the user in using MAR, and based on which the value and experiences of the technology forms in the user. Hence, the term *system* is used to refer merely to the hardware and software components (i.e., technical enablers of the service), and *application* refers to a stand-alone entity that provides the user with specific functionalities for specific purposes. Interesting for service design is not only the technological solutions per se but also what content is acquired and what activities are carried out with the help of the technology. Furthermore, *design* is here understood as the stages and activities that are explicit to the user in the interaction (e.g., service concept design, interaction design, user interface design) – rather than as the design of specific technical solutions like software architecture, algorithms or computing hardware. This thesis does not cover an entire design process of a product or service but focuses on user research that helps specifying the future concepts. Chapter 4 further clarifies the terminology based on Chapters 2 and 3.

1.3 Research Questions and Objectives

The general goal of this thesis is to create new knowledge about user experience and users' expectations in the field of mobile augmented reality. More specifically, this consists of empirical and academic objectives that are represented as research questions below, as well as practical design-oriented objectives to help transfer the research results to practice.

The two main research questions and their sub-questions are as follows:

RQ I. What do users expect of user experience of mobile AR services?

- **i.** What are the characteristics of expected user experience of MAR services?
- **ii.** What service components are expected to contribute to the UX?

RQ II. What is the user experience of current first-generation mobile AR applications?

- **i.** What are the characteristics of the most satisfying and unsatisfying experiences with such applications?
- **ii.** What are the experiential qualities of the applications?

In addition to the empirical research questions, this thesis has a practical goal of transferring the research understanding related to the abovementioned questions to relevant practices in developing mobile AR services. Specific objectives are to further operationalize and concretize the empirical findings and the resulting framework into:

Objective 1: Design implications and principles to help in designing MAR services that are experientially rich and pleasurable for the users

Objective 2: General implications and measures for subjective evaluation of the experiential aspects of MAR services and prototypes, thus helping the improvement of the created designs

The two-fold research question stems from two aspects. First, at the time of starting this research in 2008 there were little such publicly available and versatile enough MAR applications that would have allowed focusing merely on the actual experiences of functional applications. This consolidated the need for studying expectations of future services. On the other hand, during 2008-2011, the application development advanced very rapidly, which allowed also looking into the actual experience of the first consumer-targeted MAR applications. Second, two related, yet temporally differing research questions allow parallelling the empirical results to broadly identify the experiential gap between the expectations and actual experiences – hence, also the future experiential potential of current applications. However, such comparison was not chosen as a primary research interest because of the methodological challenges in comparing qualitative data from several studies with different participants, methods and contexts. Moreover, Yogasara et al. (2011) conclude that, despite the apparent usefulness of understanding 'anticipated UX', to understand the UX holistically the evaluations should also involve assessment of UX during or after the actual interaction.

1.4 Contributions

This thesis serves different audiences by presenting several types of contributions: *empirical* findings mainly intended for the AR research community, *theoretical* contributions for both the UX research and AR research communities, and *practical* contributions for practitioners (i.e., designers, evaluators, developers) of augmented reality. As shown in Table 1, each publication contributes to the entity by addressing specific research questions and focusing on certain types of contributions. The four studies that the papers are based on are described in the papers in detail and summarized in Section 4.2.

Table 1. The links between the publications and the research questions and different types of contribution of the thesis.

Paper	Link to research questions and contents of the paper	Types of contribution
I.	**RQ I.** Five focus groups to explore the potential users' expectations and needs for MAR services in two kinds of contexts: as a tourist abroad and in various situations in the everyday mobile life.	Empirical & practical
II.	**RQ I-i, RQ I-ii.** Contextual interviews to study expectations of MAR services in the context of shopping centres. Identifying characteristics of expected experience and design requirements, and contrasting them with general UX frameworks.	Empirical & theoretical
III.	**RQ I.** Online survey based evaluation of five futuristic MAR scenarios in various contexts of day-to-day activities. Focus on perceived strengths and weaknesses of the scenarios, and UX of AR overall. Both statistical and qualitative data and analysis.	Empirical
IV.	**RQ II**. Online survey based evaluation of current 1st generation MAR applications. Assessing the actual UX and perceived strengths and weaknesses. Qualitative analysis accompanied with a few statistics regarding the overall UX, and a few design implications.	Empirical & practical
V.	**RQ II-i.** Continuation of **IV**, focusing on user's descriptions of their most satisfying and unsatisfying experiences with MAR. Qualitative analysis and reflection in the light of related UX frameworks.	Empirical & theoretical
VI.	**RQ I-i**, **RQ I-ii**. Consolidation of the expectation studies from a perspective into characteristics of expected UX. Suggesting evaluation measures and discussing AR-specific UX research methodology aspects.	Theoretical & practical

The *empirical* findings about potential users' (early adopters and innovators) expectations and user experience are reported in the publications and summarized in Chapter 5. They address the research questions and thus are the basis for other types of contribution. Their value is in understanding the diversity of user experience and user expectations as phenomena in the specific field of MAR. Furthermore, the results help understanding which service components and users' background variables could affect the emergence of the expected experiences. The two-part empirical research also allows approximate exploration of to what extent do the actual user experiences differ from the expected experiences, and thus discussing how valid and relevant can research on expectations of future technologies actually be.

A significant contribution of this thesis is the *theoretical framework* describing the characteristics of expected user experience in mobile AR and the elements contributing to the overall UX (described in Section 5.3). In general, developing frameworks helps in accumulating information related to the area of interest, as well as refining and analyzing it. This theorization does not aim to quantitatively represent a generalizable theory based on which to make predictions or hypothesize causal relationships. Instead, the framework provides definitions, categorizations and concepts that are relevant to this specific area. Such conceptual and theoretical clarification is important considering the novelty and complexity of the two central concepts in the thesis – user experience and mobile augmented reality. As brought up in Chapter 3, user experience and users' expectations have been studied very little in the field of AR, and no other similar categorizations of expected experience in this field exist. A minor contribution lies also in comparing the MAR-specific UX categories with certain general UX frameworks. Finally, the framework allows proposing appropriate agendas for future research and development in the field of MAR.

The *practical* contribution relates to further concretizing the empirical and theoretical contributions. To clarify, Table 1 indicates which papers explicitly provide such practical discussion or implications. Most importantly, Chapter 6 provides design implications for the concept design and UX-related refinement of MAR services. In addition, the theoretical framework not only provides constructs and themes to be considered but has also been concretized to subjective statements to be used in evaluation of the UX in MAR (paper **VI**). The evaluation statements can be used to identify experiential aspects that require further improvement as well as to assess how well a service achieves the set experiential targets set.

1.5 Structure of the Thesis

In Chapters 2 and 3, the research questions and the research approach are further justified in the light of theory and related work about user experience and augmented reality.

Chapter 2 elaborates the concepts of experience, user experience and expectations, as well as their importance in design. Various frameworks and models are presented with regard to aspects relating to and influencing UX, how it relates to other relevant concepts like user acceptance, usability and customer value, and what practices exist related to designing and evaluating user experience. The

chapter concludes that there is a need to do in-depth research on UX in specific technological fields and application areas.

Chapter 3 introduces various 'reality concepts' (e.g. mixed reality) and concepts related to ubiquitous computing as the background of MAR. The various technologies behind MAR are briefly introduced, and a summary of earlier application areas of AR is presented. Furthermore, results of user studies and usability and UX considerations in AR and related areas are described and contextualized to this work. The chapter highlights that little is known about what potential users expect of the multifaceted nature of MAR, especially regarding user experience.

Chapter 4 continues depicting the research scope, approach and process on a concrete methodological level. As the potential areas of research in UX and MAR are extensive, various focusing decisions are described grounding on the lessons learned in the related work in Chapers 2 and 3. The chapter summarizes the different studies conducted as part of the thesis, as well as their overall research procedures, participants, and the data gathering and analysis methods utilized in them.

The *Results* of the thesis consist of Chapters 5 and 6. First, Chapter 5 summarizes the empirical findings from the publications, focusing on addressing the research questions – especially with regard to the characteristics of experience and various elements that play a role in the actual and expected UX of MAR. A summarizing framework of the results is presented in Section 5.3, grounding on the conceptualizations described in Sections 5.1 and 5.2. Second, Chapter 6 discusses the results in the light of theories and practical implications. First, the chapter further discusses the differences between expectations and actual experiences and contrasts the identified categories of experience with earlier theories and frameworks related to UX. Second, the practical value of the thesis is contained especially in Section 6.3, which bridges the results into design implications for future MAR services. The implications to evaluation of UX of MAR services are described extensively in Paper **VI** (two sets of subjective statements) and therefore are not recapitulated in this introductory part of the thesis.

Chapter 7 summarizes the overall quality and value of the research, discusses the methodological limitations, and reflects how well the research questions and objectives have been addressed. It sums up the thesis and concludes the main take-away points. Finally, insights for future research around UX and mobile AR are presented.

The original publications are appended in the end of the thesis in order from **I** to **VI**.

2. User Experience and Expectations

This chapter describes the phenomenon of user experience and its facets from several perspectives. A fundamental target is to discuss and define concepts and meanings of terms, i.e., the vocabulary that is used throughout the thesis. After an introduction to the topic, the concept of *experience* is defined, discussing also different types of experiences as human reactions. This is followed by a contextualization of experience into the scope of interactive technology, hence defining *user experience*. The different characteristics of user experience from relevant literature are discussed in 2.3.2. A special focus is put in the temporal perspective of UX (Sections 2.3.5 and 2.4) in order to specify the concept of *user expectations*. Finally, related work on design and evaluation of UX is presented.

2.1 User Experience in Brief

Put simplistically, user experience (UX) involves the characteristics, facets and processes attributed to the concept of 'experience', but it narrows down to the scope of interaction with technology. In brief, the following summarizes the conceptual definitions of UX that are described in this chapter:

> User experience refers to the end users' subjective experience (e.g. emotional, physical or behavioral reactions) that is formed in interacting with an interactive technological artifact.

Regarding the overall background and history of UX, the elements and regularities of human experience have increasingly gained interest in the research and design of interactive systems over the last few decades. Experience as a *quality attribute* is considered as a critical asset in global business: in order to success in the current and future world, companies must orchestrate memorable events for their customers, and that the memory itself becomes the product - the experience (Pine & Gilmore 1999). Oppelaar et al. (2008) suggests that good usability has become an axiomatic feature and is not enough when designing successful products. Similarly, Rifkin (2000) emphasizes that people do not value commodities as things in themselves but for the quality of the experience they provide.

Consequently, the design challenges have shifted from providing reliable, efficient and usable functionalities with a competitive price towards providing the users with pleasurable experiences, exceeding their expectations and supporting fulfillment of fundamental human needs, such as identifying with or socializing through a product. Both the global competition (the economical perspective) and people's inherent needs to enjoy, evolve and thrive (the humanistic perspective) have brought about needs for, as Hassenzahl (2003) puts it, "more holistic perspectives and an enrichment of traditional quality models with non-utilitarian concepts, such as fun, joy, pleasure, hedonic value or ludic value." These premises have allowed the advent of *user experience* as a new concept to denote the experiential aspects in use of technological products or services. Overall, the development from human factors research, Kansei engineering (Nagamachi 1989), usability, user satisfaction and other relevant older concepts to UX is an interesting and winding path. Profound analyses of this progression can be found from, e.g., Mahlke (2008, 23) and Battarbee (2004, appendix).

The concept of user experience has been readily adopted by the multidisciplinary HCI community. It is actively researched as a phenomenon, new practices and methods are developed around it, and it has become a new conceptual instrument with which to advance the user-centered design stance. New concepts are constantly created and older relevant ones are merged and contextualized under the umbrella of user experience. Examples of such are pleasure (Jordan 2002), aesthetics (Wright et al. 2008), emotions and hedonism (Desmet 2002, Hassenzahl 2003).

Related to its theoretical backgrounds, UX can be contemplated through various disciplines (Forlizzi & Battarbee 2004), especially the following:

- *Philosophy and religion:* understanding the qualitative and definite aspects of the concept of experience and experiencing as an activity (e.g. Dewey 1925)
- *Psychology:* dealing with emotions, cognitive processes and types of experience that are consequences of interaction
- *Sociology:* investigating what external elements affect how an experience forms, for example, culture and social environment
- *Marketing:* often interested in repurchase, use continuance and how a product can create positive affects and commitment in a consumer, (e.g., O'Brien & Toms 2008)
- *Engineering:* usually focused on identifying and developing product characteristics and technical solutions that facilitate a positive experience (i.e., a product-centered view)

In addition to these overall perspectives, Hassenzahl and Tractinsky (2006) identify three main threads or facets of research that characterize user experience. The first thread deals with addressing human needs *beyond the instrumental* in order to create a more complete, holistic view to HCI. This thread emphasizes that non-instrumental needs like surprise, intimacy, beauty, and personal growth should be concerned in addition to the traditional instrumental needs like usability and efficiency. The second thread concerns *emotion and affect*, understanding them as phenomena, and how products could create positive emotions like friendship, joy, and pride – not only avoiding negative emotions like sadness, frustration or loneliness. The third – the experiential – perspective on UX emphasizes its *situatedness and temporality*: the experience is a unique combination of elements from the product, the internal states of the user, and the purpose and situation in which the product is used.

2.2 The Concept of Experience

Overall, the concept of experience is often seen as complex and holistic, depending on the subject, and something to do with human's mental reactions – independent of the discipline. In the following, various interpretations and theories are presented to clarify the concept of experience.

Merriam-Webster[1] provides several definitions for 'experience', of which two are presented below:

> "Something personally encountered, undergone, or lived through"
>
> "The act or process of directly perceiving events or reality"

[1] Merriam-Webster encyclopedia: www.merriam-webster.com/dictionary/experience , Accessed 29.2.2012

The widely cited philosopher John Dewey (1934) consolidates the above: "an experience is a product, one might almost say bi-product, of continuous and cumulative interaction of an organic self with the world." This emphasizes the *interaction* between the subject, the one who experiences, and the object, that is, the entire world around it with all its characteristics and sources of stimuli for people. This also implies that experience is a *subjective* phenomenon (i.e., depending on the actor), a process that is relevant for the subject itself. Kahnemann (1999) emphasizes the mental processes and outcomes in his description of experience as "a stream of feelings, thoughts and action; a continuous commentary on our current state of affairs". The mental interpretation process gives an experience its *meaning and value*. Applying from Hassenzahl (2011), psychologically an experience emerges from the integration of mental and physiological actions and representations like perception, motivation, and cognition into an inseparable, meaningful whole.

Experiencing has also a *function*: "Every experience is a moving force. Its value can be judged only on the ground of what it moves toward and into" (Dewey 1938). For example, there is always experience behind concepts. Concepts and the terms in different languages base on bottom-up definitions from empirical perceptions and experiences. After all, human experience is the ultimate source for all knowledge. Dewey (1925) argues that experience is a double-barrelled word; similarly as many other great and extensively used words, such as 'life' and 'history'. It includes *what* people do and suffer, strive for, believe, like etc. but also *how* they do and suffer, desire, enjoy, see, imagine etc. – i.e., the processes of experiencing. It recognizes "no division between act and material, subject and object, but contains them both in an unanalyzed totality" (Dewey 1925). Overall, Hassenzahl (2010, 8) nicely summarizes the different facets of experience:

> "an episode, a chunk of time that one went through [...] sights and sounds, feelings and thoughts, motives and actions [...] closely knitted together, stored in memory, labelled, relived and communicated to others. An experience is a story, emerging from the dialogue of a person with her or his world through action".

Furthermore, experience is *dynamic and evolving*. "The quality of any experience has two aspects. There is an immediate aspect of agreeableness or disagreeableness, and there is its influence upon later experiences." (Dewey 1938). Experience is not only interaction between people and the surroundings, but also historical interaction between different single experiences: the present experience is built on earlier experiences and the expectations and attitudes that they have created (Ibid).

In other words, experience in general is distinguished from "an experience" (Dewey 1934, Forlizzi & Ford 2000). 'Experience' occurs continually like a stream, as we are always involved in the process of living, perceiving, feeling and thinking. "An experience" occurs when a temporally specified activity is finished (a problem solved, a book is read, a game is played through, a conversation is rounded out etc.) and fulfillment and closure conclude the experience. Such are individual and singular, each having its own beginning and end, its own plot, and its own singular quality that pervades the entire experience, no matter if the experience was something great or of small importance. They allow feeling powerful emotions, assessing our values, and possibly making changes in our behavior. In addition, "experience as story" (Forlizzi & Ford 2000) is something that is communicated by the user

in story form, a vehicle to condence and remember experiences in order to communicate them to certain audiences. This also emphasizes the functional value of experience: first-hand experiences are often recounted and shared with others, thus making them worthwhile to others too.

Understanding the scope of different types of human experiences is an important but challenging task. For example, although the following examples are all positive and moderately rare in frequency, the qualities are very different: (1) a mentally and physically intensive and immersing experience like a bungee jump, (2) feeling granted absolution after having regretted something for a long time, (3) understanding a challenging philosophical concept for the first time. Perhaps because of the inherently multidisciplinary and wide-ranging nature, there does not seem to be widely accepted theories about the different types of experience. Merely the Wikipedia[1] description of 'experience' demonstrates the infinite extent of experience: mental, emotional, physical, unconscious, spiritual, religious, behavioral, vicarious and virtual. Categorizations like this could be understood as *components*: each experience can have qualities from the different components with varying strengths. What is more, they interact – e.g. compensate or strengthen – with each other. For example, Dewey (1934) argues that the bodily states resulting from an experience might further deepen the quality and intensity of the experience itself.

All in all, defining experience as nearly everything that takes place in human life is hardly useful as a conceptual framework to focus and drive research or development. Therefore, when considering the experiences that take place especially in human-technology interaction – or "technology as experience" (McCarthy & Wright 2004) – the concept of *user experience* has been introduced.

2.3 The Multifaceted Nature of User Experience

Recently, the concept of *user experience* has undergone a thorough specification and discussion from various viewpoints in the multidisciplinary HCI community. The concept still creates vivid academic and practical discussions – with regard to its nature and framing, as well as the consequences to design and evaluation practices. A part of this comes down to the all-inclusiveness and multidimensional nature. User experience can refer to interactions with various temporal lengths, intensities, levels of intention, sensory modalities, and types of experiential outcomes. It can refer to the process as well as the consequences of interacting. Furthermore, it is not only defining what it is or what it is not that is complex but also developing methods and processes that support designing for a satisfying user experience. Roto et al. (2011) identify that there are various viewpoints of theories and frameworks that demarcate and discuss for example:

(1) different types or characteristics of experience taking place in interaction with technology
(2) product features, contextual aspects or intrinsic human values and needs that create or contribute to the different experiences
(3) methods and approaches to envisioning, representing and evaluating UX

In the following, relevant theories and studies about the aforementioned facets are presented and the concept of UX is contrasted with concepts of usability, user acceptance, and customer value.

[1] Wikipedia Encyclopedia: en.wikipedia.org/wiki/Experience , Accessed 4.3.2012

2.3.1 Defining the Concept of User Experience

The UX white paper (Roto et al. 2011) concludes that user experience differs from experience in general by explicitly referring to the experiences derived from *encountering systems*. Here, 'encountering' refers to "using, interacting with, or being confronted passively" (Ibid). 'System' denotes products, services and artifacts that a person can interact with through a user interface. A 'user' means a human agent, i.e., the subject, who uses the system. In this thesis, 'user' is often used as a synonym for *'end user',* which distinguishes the user for which the product is designed from other users who are making the product possible for the end user (e.g. administrator, customer).

Apart from a conceptual dissection like above, there exist various holistic definitions for user experience. A recent ISO standard (2010) defines UX holistically as:

> "A person's perceptions and responses that result from the use or anticipated use of a product, system or service."

This clearly relates to the concept of experience but is contextualized to refer to the experiences evoked from products, systems or services – be they technological and interactive products, immaterial services, or digital artefacts like games. Furthermore, Roto (2006) emphasizes that "using means that the user not only senses the system, but also has the opportunity to manipulate or control the system". She argues that systems not controllable by the end user (e.g. roller coasters) do not create a user experience but 'plain' experience, and hence should not be regarded as UX.

The glossary of usability Body of Knowledge (UPA 2012) defines user experience as "Every aspect of the user's interaction with a product, service, or company that make up the user's perceptions of the whole". This definition includes also the company, such as the producer of a product, as a source of the experience, similarly as the definition by Nielsen Norman Group (2012) does: "User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products". Sward and Macarthur (2007) emphasize value as the outcome of interaction: "UX is the value derived from interaction(s) [or anticipated interaction(s)] with a product or service and the supporting cast in the context of use (e.g. time, location, and user disposition)". Here, they recognize both actual value (e.g. efficiency) and perceived value (e.g. satisfaction, aesthetic, entertainment).

Regarding other closely related concepts, Hekkert (2006) talks about *product experience*, taking a perspective on affects: "the entire set of affects that is elicited by the interaction between a user and a product". Product experience can be seen to have a slightly narrower scope than user experience, as not all technological and interactive things are products. *Brand experience*, on the other hand, includes not only interaction with the branded products, but also interaction with the company, its other products and services, which makes brand experience a slightly broader concept than user experience (Law et al. 2009). Furthermore, the term *service experience* exists as well but needs to be used with care, as it can, in a broad sense, refer to face-to-face services (e.g. in a restaurant), public services (e.g. city infrastructure), as well as digital services on the Internet (e.g. online shops) or anything in between. To clarify these differences, Law et al. (2009) argue that experiences of, for example, events, space, brand, art, exercise, or face-to-face interaction do not belong under the umbrella of UX.

Overall, although the concept of UX is still rather young, there are a few common key assumptions that are widely accepted (Hassenzahl et al. 2010, Law et al. 2009, Roto et al. 2011). Law et al. (2009) carried out a survey with 275 UX researchers and practitioners to gather views on UX and to understand, scope and further define the concept. They conclude that UX is generally regarded as:

- *Subjective*: the evoked experience, its characteristics and valence differ from person to person – even though the activity, system and context of use were the same.
- *Context-dependent*: the same interaction can bring about different experiences in different physical, social and cultural situations
- *Dynamic*: the overall experience cumulates and changes over time

2.3.2 Characteristics of User Experience of Technology

In addition to the *holistic definitions* of the concept of user experience, various frameworks provide categories and concepts to help characterizing, identifying and classifying different experiential reactions, i.e., *types* of user experience. Although there is continuous discussion whether an experience can be modeled, reduced to specific categories or quantified (i.e., the qualitative and quantitative standpoints, as referred by Law 2011), I argue that the following categorizations helps understanding the different types of UX, hence also the results of this thesis. In grouping the following frameworks, the division to 'user-centered', 'interaction-centered' and 'product-centered' frameworks priorly used by Forlizzi and Battarbee (2004) is applied.

User-Centered Frameworks

User-centered models are the most frequent ones as experience after all is about the user's internal reactions and consequences. To start with, Desmet and Hekkert (2007) propose a framework about product experience and its various manifestations: (1) *subjective feelings:* the conscious awareness of the change in core affect, (2) *behavioural reactions:* behavioural tendencies like approach, avoidance, inaction, (3) *expressive reactions:* e.g., smiling and other facial, vocal and postural expressions, and (4) *physiological reactions:* e.g., sweat production and other activities of the autonomic nervous system. These are important facets of how the experience becomes explicit or palpable – for both the subject and other people – and what are its instant consequences in a person.

Norman (2004) proposes three types of experience to consider as information processing levels in emotional design: *visceral*, *behavioral* and *reflective*. First, the visceral level refers to the automatic, biologically determined, prewired level that marks the start of affective processing with rapid judgments (e.g., what is good, what is bad, what to approach). Second, the behavioral level is the site of most human behavior, containing the brain processes that control our everyday behavior. Third, the reflective level is the contemplative part of the brain. The reflective level does not have direct access either to sensory input or the control of behavior but it watches over, reflects upon, and can bias the behavioral level in long-term. The reflective level can enhance or inhibit the behavioral level, which, in turn, can enhance or inhibit the visceral level.

Desmet and Hekkert (2007) distinguish between three types of *product experience*. First, the *aesthetic experience* refers to the gratification of the senses, i.e., how the sensory and perceptual system reacts to the product's appereance, tactile attributes, and sounds and smells created. It is the degree to which the perceptual system "manages to detect, e.g., structure, order or coherence and assess the product's novelty/familiarity". Later, *sensory experiences* have been separated from this, focusing on the instant sensory reactions: visual, auditive, haptic, olfactory and gustatory (Schifferstein & Hekkert 2011). Second, *experiences of meaning* refer to cognitively processed experiences like control, luxury and attachment. The experience goes through processes like semantic interpretation and symbolic association, which makes it possible for people to "recognize metaphors, assign expressive characteristics and assess the personal or symbolic significance of products". The meaning can be based on various features of the product (e.g., cultural value, functionalities, how it supports one's identity). Third, *emotional experience* refers to affective phenomena like happiness, disgust, fear, pride and surprise. Emotions are functional: pleasant emotions pull people to beneficial things and unpleasant emotions push from those that are detrimental.

Jordan (2002) takes a perspective on the role of pleasure in product experience. Based on a general approach to pleasure by Tiger (1992), Jordan distinguishes four types of pleasurable experience, defined as follows: (1) *Physio-pleasure*: related to body and senses, (2) *Psycho-pleasure*: related to the mind and emotions, (3) *Socio-pleasure*: related to relationships and status, (4) *Ideo-pleasure*: related to values and attitudes. These can be seen as different overall characteristics of an experience.

Building on Dewey's pragmatics, Wright et al. (2008) describe the holism of experience as a braid made up of four intertwining threads that are common to all experience: the sensual, emotional, spatio-temporal, and compositional. First, the *sensual thread* is concerned with our sensory, bodily engagement with a situation, the concrete and visceral characters of experience that is grasped pre-reflectively in the immediate sense of a situation (e.g., look and feel of a product, warmth of a summer day). Second, the *emotional thread* refers to "judgments that ascribe to other people or things an importance with respect to our needs and desires". Our sensations of frustration, desire or satisfaction are directed at another person or thing. People can reflect on their own emotions but also others' emotions. The interplay of the sensual and emotional threads shapes a satisfactory outcome of the experience. Third, the *spatio-temporal* thread highlights that experience always relates to a particular situation ("place") at a particular time. Fourth, the *compositional* thread is "concerned with the narrative structure of an experience, how we make sense of the relationships between the parts and the wholes of an encounter." In an unfolding interaction, it refers to what might happen, what does happen, the consequences and causes, thus making sense of control and agency of actions.

As seen above, the frameworks are partially overlapping although they might represent different standpoints or premises. Buccini and Padovani (2007) clearly agree with this as they pursue creating a consolidated model of product experience. They present a typology with six categories, which perhaps is not all-inclusive with regard to the entire diversity of the above-mentioned frameworks but serves well in summarizing the most central types of experiences that can take place in interaction with technological products and services:

(1) Experiences related to senses: instinctive, with low cognitive performance (e.g. touch, vision)
(2) Experiences related to feelings: subjective emotional reactions like joy and anger
(3) Social experiences: experiences that happen between individuals but are intermediated or simulated by products
(4) Cognitive experiences: related to the thoughts, reflection and interpretation of the user (e.g., based on semantic and symbolic product features)
(5) Use experiences: related to usability and functionality of the products (e.g. convenience)
(6) Motivational experiences: when the use of a product is responsible for a certain behavior of the user (e.g., a bicycle that motivates the user to exercise)

Interaction-centered frameworks

Interaction-centered models focus on the type of interaction and the user's degree of involvedness with the product. In identifying, evaluating or designing for the experiences that a technological system creates it is important to understand that different kinds and levels of interaction can result in slightly different types of experiences. For example, Desmet and Hekkert (2007) argue for three different types of human-product interaction that affect the characteristics of the resulting experience. First, *instrumental* interaction means using, operating and managing products with an instrumental goal in mind. Second, *non-instrumental* interaction refers to interactions that do not directly serve a function, such as playing with or caressing the product. Third, *non-physical* interaction refers to remembering, fantasizing about or anticipating the use. All of the user's actions and processes contribute to the experience: e.g., physical actions and cognitive processes like exploring, remembering and comparing.

Forlizzi and Battarbee (2004) discuss different levels of and targets for the interaction. First, *fluent* interactions are the most automatic and well-learned ones, usually mostly unconscious and not competing for attention or other cognitive processes (e.g., riding a bicycle, talking as a physical operation). Second, *cognitive* interactions focus consciously on the interaction at hand, possibly leading to new knowledge, confusion or errors (e.g., trying to identify the flushing mechanism of a toilet in a foreign country, playing an unfamiliar musical instrument, using a language that is not your mother tongue). Third, *expressive* interactions help users form a relationship to the product or service (e.g., modification or personalization of the product or figuring out new ways of using it for new purposes).

Finally, Pine and Gilmore (1998) discuss two dimensions related to the engagement of the user: (1) *customer participation*, ranging from passive to active participation (e.g., those following a ski race and those attending to the race), and (2) *connection*, ranging from absorption to immersion (e.g., those in the grandstand of a sports event vs. those in the infield).

All in all, different types of interaction allow very different types of experiences and should hence be considered, e.g., when assessing the scope of possible experiences in a specific interaction event or when designing for experiences that a technological system would evoke. This further implies that experiences are dependent on the context and the task: one product or service with the same user might generate different experiences depending on, for example, how intensive the use is, what is the target of the interaction and in what role the user is in their social context.

Product-centered frameworks

The product-centered frameworks put emphasis on the product characteristics or qualities that make it possible, catalyze or evoke specific experiences. Rather than addressing a user's internal reactions and emotions, such frameworks focus on understanding how product characterstics – with varying levels of abstraction – affect UX and how to assess the 'goodness' of a product in terms of UX.

Perhaps the most well known is the framework by Hassenzahl (2003). He distinguishes between two main perceptions of product quality: *pragmatic* and *hedonic*, which create the abstract consequences, i.e., experiences, in the user: *appeal*, *pleasure*, *satisfaction*. The pragmatic quality (or *manipulation*) refers to the product's ability to support achievement of behavioral goals, such as need to find information about a person (e.g., product's utility value, usability, controllability). Hedonic quality emphasizes psychological well-being and refers to the product's features or aspects that appeal to one's desire of pleasure and avoidance of boredom or discomfort. Hedonic quality is further divided into three aspects: (1) *stimulation*: enabling personal development, proliferation of knowledge and raising the user's attention and motivation, (2) *identification*: facilitating self-expression and building one's identity with the help of the product, and (3) *evocation*: provoking precious memories (e.g., retro computer games or vintage instruments). To discuss these concepts' relevance in practice, Chitturi et al. (2008) showed that products that meet or exceed *utilitarian* (pragmatic) needs enhance mostly customer *satisfaction*, whereas products that meet or exceed *hedonic* wants enhance mostly customer *delight*.

Jääskö and Mattelmäki (2003) present their framework of qualities of user experience, in which they identify relevant product features like *appereance* (aesthetics, physical ergonomics), *user interface* (cognitive ergonomics), *product meaning* (attachment, memories), and *product novelty* (relation to trends and other products). In addition, they pay attention to the interaction, the environment (context) and user's personality (e.g. life-style, attitudes and values) as factors affecting the wholeness.

2.3.3 Emotions and Feelings in User Experience

As shown in the previous frameworks, emotional reactions are an important component of the experiential outcome in use of technology. The following briefly discusses what emotions actually are.

Psychology examines emotions from a scientific perspective by treating them as mental processes and behavior. Emotions fundamentally involve (1) *physical arousal*: e.g., perspiration, a lump in one's throat, (2) *expressive behaviors* like avoidance or approach, facial expressions or tone in speech, and (3) *conscious experience*: e.g., feeling of anger, joy or pride (Myers 2004). Emotions are usually considered as universal, that is, independent of the culture or background of the person. Kleinginna and Kleinginna (1981) found over 100 definitions and propose a consensual definition. Emotion is a complex set of interactions among subjective and objective factors, mediated by neural-hormonal systems, which can:

(1) Give rise to affective experiences, such as feelings of arousal or pleasure/displeasure
(2) Generate cognitive processes, such as emotionally relevant perceptual effects, appraisals and labeling processes
(3) Activate widespread physiological adjustments to the arousing conditions
(4) Lead to behavior that is often, but not always, expressive, goaldirected, and adaptive

There exists a body of theorizations about the categories of emotions. Different psychologists acknowledge different human reactions as emotions, and slightly different terms are used to refer to similar concepts. A widely cited example is the categorization by Ekman and Friesen (1982), consisting of six emotions: *anger*, *disgust*, *fear*, *joy*, *sadness* and *surprise*. Izard (1977) lists many of the same but also a few additional: *anger*, *contempt*, *disgust*, *distress*, *fear*, *guilt*, *interest*, *joy*, *shame* and *surprise*. Other proposed emotions include, for example, *grief*, *pain*, *courage*, and *anticipation*. Some authors categorize the emotions in structural models that aim at specifying the differences in abstraction levels between different terms. For example, Parrot (2001) divides the anger-related emotions to *irritation*, *exasperation*, *rage*, *torment* etc., and these further to *aggravation*, *agitation*, *annoyance*, *frustration*, *fury* etc.

Desmet (2002) discusses emotional reactions resulting from use of products and identifies five categories: (1) *surprise* emotions and amazement like awe and astonishment, (2) *instrumental* emotions, such as disappointment and satisfaction, (3) *aesthetic* emotions related to intrinsic pleasantness, e.g., disgust, attracted to, (4) *social* emotions like indignation and admiration, and (5) *interest* emotions, such as boredom and fascination. Here, the value is in classifying various emotions under the five categories that especially relate to use of products.

Often, when talking about emotions, the concepts of *moods* and *feelings* are mentioned as well. Emotions are instinctual reactions or responses to external events or to cognitive appraisal of events, and therefore short enough to be measured in seconds. Feelings are often regarded as the conscious experiences of emotional states: e.g., the feeling of being bad-tempered as a consequence of the emotional states of anger. A mood is a relatively long-lasting emotional state and differs from simple emotions in that they are less specific, less intense, and less likely to be triggered by a particular stimulus or event (Thayer 1989). Moods as longer-term states affect emotions by, e.g., strengthening or weakening the valence of the emotion. Furthermore, personality characteristics, such as openness or neuroticism, affect both the moods and emotions by tendencies to feel specific emotions.

To summarize, emotions, feelings and moods are inherent elements of UX and have an important role in how people perceive the world (Norman 2004). The emotional component of an experience easily becomes dominant in encounters where the user feels, e.g., frustration or surprise because of the technology. Emotions bring about methodological challenges like the subjectivity, the dynamic and short-term nature, and the data being challenging to analyse. For example, Isomursu et al. (2007) present a study in which five different self-report methods for measuring emotions were used to collect information about emotional responses to mobile applications. They identify various challenges in each method and, based on the lessons learned, propose a framework for selecting the methods for various research purposes.

2.3.4 Building Blocks of User Experience

The experience is hardly ever a property or consequence of merely the technological system: it is constituted in the specific user's interaction with the system – or its particular features – in a certain situation with certain premises. This multi-facetedness is central in the definition by Hassenzahl and Tractinsky (2006): "UX is a consequence of a user's internal state [...], the characteristics of the

designed system [...] and the context (or the environment) within which the interaction occurs". Therefore, it is possible to identify features and characteristics in the product, the user, the user's activity, and the environment that affect, facilitate, rule out, or modify an experience or make it possible to happen. Figure 2 depicts various characteristics that can play a role in the formation of the UX. It consolidates multiple frameworks – both based on empirical learnings and conceptual work (Arhippainen & Tähti 2003, Clarkson 2008, Forlizzi & Ford 2000, Hartmann et al. 2008, Hassenzahl 2008, Hassenzahl & Tractinsky 2006, Hekkert & Leder 2008, Mäkelä & Fulton Suri 2001, Roto 2006).

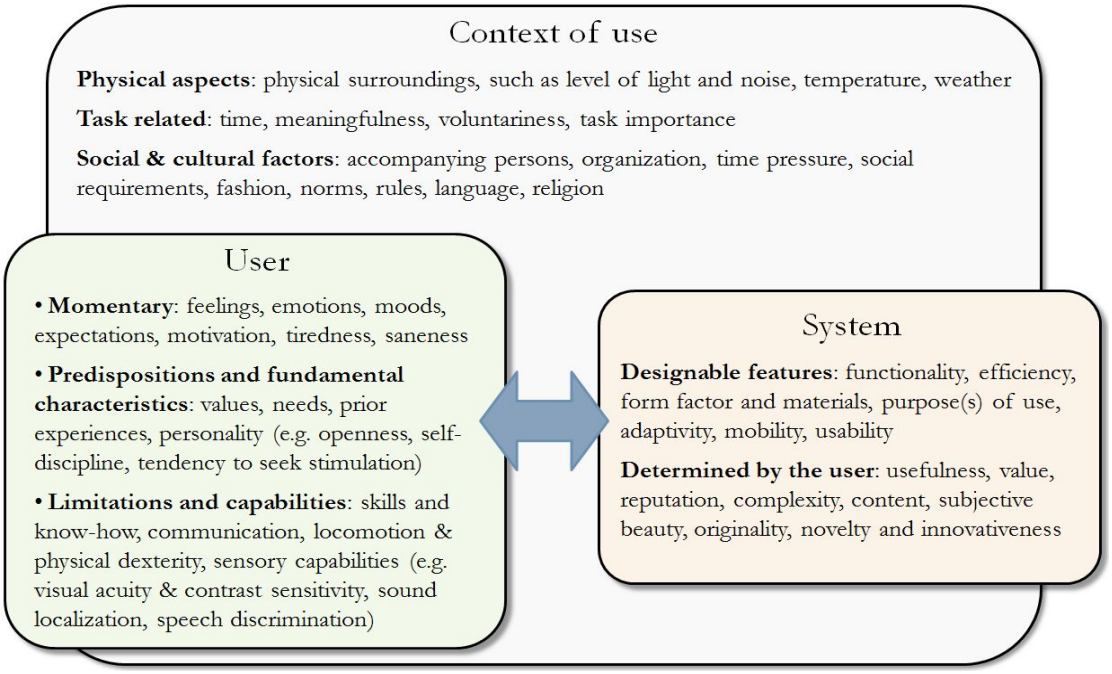

Figure 2. A consolidation of aspects affecting UX: Characteristics of user, system and context.

The Formation Process of UX

In addition to understanding the characteristics of experience and the aspects affecting it, there are frameworks that model the formation process of UX. Hassenzahl (2003) presents a model where the different product features are ascribed to certain apparent product attributes (Figure 3). These product characters like content, functionality and interaction have specific consequences in the user, such as appeal, pleasure and satisfaction. Naturally, they also depend on the situation and the person.

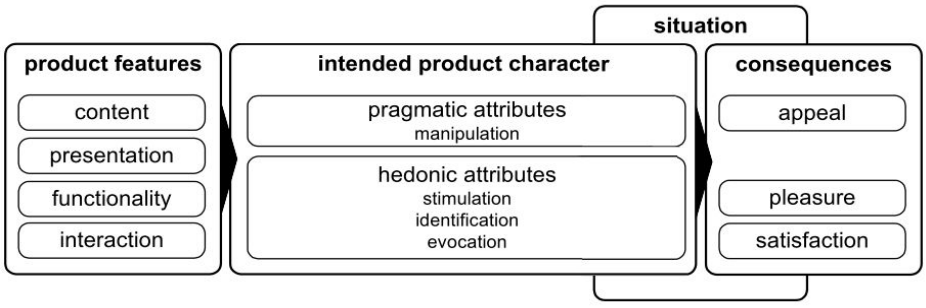

Figure 3. UX as a process from product features to apparent product characters, the situation of use, and experiential consequences (adapted from Hassenzahl 2003).

Mahlke (2008) presents a similar model with some refinements. Instead of pragmatic and hedonic qualities, he identifies (1) instrumental qualities like utility and usability, (2) emotional reactions like subjective feelings, motor expressions, cognitive appraisals and behavioral tendencies, and (3) non-instrumental qualities like aesthetic aspects, symbolic aspects and motivational aspects. In addition, he regards these to cause the consequences that involve also, e.g., choice between product alternatives and usage behavior. Overall, both of the frameworks help to understand the starting points, components and consequences of UX in general.

The Relation to Human Needs and Values

UX theories often take it granted that the interaction between human and technology 'just happens'. However, as most human actions that HCI is interested in are deliberate, there must be internal motivating forces that bring about the activity. Hassenzahl (2008) addresses this in one of his conclusions: "Good UX is the consequence of fulfilling the human needs for autonomy, competency, stimulation (self-oriented), relatedness, and popularity (others-oriented) through interacting with the product or service…" McCarthy and Wright (2004, 85) further state that all our actions are "shot through with values, needs, desires, and goals". In addition, Kankainen (2003) presents "motivated action" to be understood as a need that sufficiently directs the user to act in a specific way. The motivator could be a fundamental human *need*, a personal *value*, an *emotion*, or some other psychosocial state. Hence, the following discusses the concepts of *needs* and *values* as starting points of UX.

From psychological perspective, it seems certain that needs, such as physiological hunger or need for self-esteem, are targeted to enhance personal thriving, and that they are motive forces (Ryan & Deci 2000, Sheldon et al. 2001). Based on multiple research cases, Sheldon et al. (2001) propose a set of ten significant psychological needs. The relevance of this framework to HCI has been studied by, e.g., Hassenzahl et al. (2010). They found out that experiences could indeed be categorized by the primary need they fulfil. The following summarizes the need categories and links them to the UX frameworks by Jordan (2002) and Hassenzahl (2003) presented earlier (according to Hassenzahl et al. 2010):

(1) Autonomy-independence: Feeling like you are the cause of your own actions rather than external forces cause your actions
(2) Competence-effectance: Feeling that you are very capable and effective in your actions (relates to psycho-pleasure and pragmatic)
(3) Relatedness-belongingness: Feeling that you have regular intimate contact with people who care about you (socio-pleasure)
(4) Self-actualization-meaning: Feeling that you are developing your best potentials and making life meaningful rather than feeling stagnant (ideo-pleasure and evocation)
(5) Security-control: Feeling safe and in control of your life rather than feeling uncertain and threatened by your circumstances
(6) Money-luxury: Feeling that you have plenty of money to buy most of what you want

(7) Influence-popularity: Feeling that you are liked, respected, and have influence over others (socio-pleasure and identification)
(8) Physical-bodily: Feeling that your body is healthy and well-taken care of rather than feeling out of shape or unhealthy (physio-pleasure)
(9) Self esteem-self-respect: Feeling that you are a worthy person who is as good as anyone else rather than feeling like a 'loser'
(10) Pleasure-stimulation: Feeling that you get plenty of enjoyment and pleasure rather than feeling bored and understimulated by life (psycho-pleasure and stimulation)

Similarly as 'needs', *value* is a highly polysemous word, its meaning oscillating between concepts as distant as economic return and moral standards (Boztepe 2007). For the introductory purposes of this section, the focus is on the notion of values as conception(s) of what is ultimately good and eligible in human life (as discussed by, e.g., Graeber 2001). Schwartz and Bilsky (1987) provide examples of such, related to, for example, *excitement and challenge in life*, *achievement*, *safety*, *harmony*, *conformity*, *tradition* and *benevolence* (i.e., enhancing the welfare of ones communities). The eligibility perspective is central also in the proposition of Kujala and Väänänen-Vainio-Mattila (2009): *user values* describe "users' psychological values that affect their views as to what kind of purpose, functions and characteristics are important to them in a certain usage situation and context". Their summary of user values in literature include *social values* like achievement, honesty, status and equality, *emotional/hedonistic values* like enjoyment and pleasure, *stimulation and epistemic values* like curiosity, novelty and excitement, *traditional values* like respect and commitment, *safety values* like security and social order, and *growth and self-actualization values* like creating and independent thought and action.

Finally, regarding the actualization of needs and values, Demir et al. (2009) identify various components that can be seen as 'appraisals'. Products that match users' concerns like needs, goals and values are appraised as beneficial and the mismatching as harmful. The appraisal components consist of, for example, *motive consistency* (how does a situation relate to what the user wants and what her motives are), *intrinsic pleasantness* (the sensorial pleasantness of an object), *expectation confirmation component* (does the actual outcome of an event confirm or violate the user's explicit expectations), *agency* (who is responsible for this event – oneself, another person or thing, or the general circumstances) and *standard conformance* (is the situation in line with social norms and standards).

2.3.5 The Temporal Nature of User Experience

An important aspect in understanding the different levels of abstraction when characterizing UX is its *temporality* or *time span* (Law & Schaik 2010, Roto et al. 2011). Following the footsteps of Dewey, the UX whitepaper by Roto et al. (2011) distinguish between 'experiencing' and 'a user experience'. The dynamic nature of UX is emphasized with the term *experiencing* – it refers to the constant stream of perceptions, interpretations and emotions of an individual person in the interaction with technology. With '*a user experience*' they refer to an encounter with a system that has a beginning and an end – a period of use (e.g., using a navigator to get from place to another). Rather than its dynamic nature, this term emphasizes the outcomes and memories of experiencing.

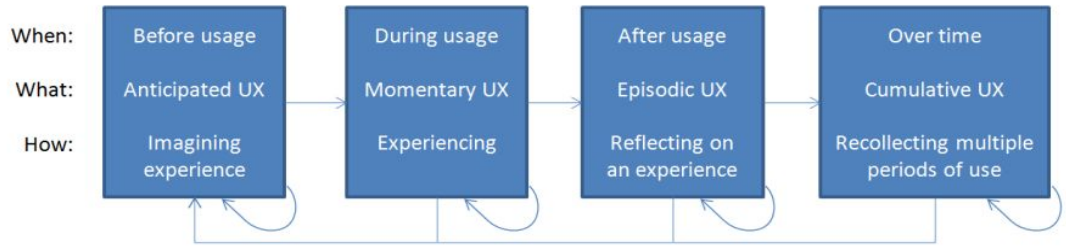

Figure 4. The time spans of UX and the internal process taking place in the different time spans (Roto et al. 2011).

The UX white paper (Roto et al. 2011) continues this discussion by presenting four time spans of UX (Figure 4). First, the experience can be *anticipated*, i.e., imagined in advance. Because of its central role in this thesis, it is further explicated in Section 2.4. Second, a *momentary* experience refers to a specific change of a short-term feeling during interaction (often sensory, emotional or visceral experiences). Third, *episodic* experience refers to the appraisal of a specific episode of use or activity, often considering, e.g., usefulness, value of product, convenience of use and privacy. Finally, *cumulative* experience covers the overall views on a system as a whole, after having used it for a while (e.g., relationships with products, trust, societal implications). Here, the product might be also contrasted with other products and its value assessed through social processes. Overall, such inspection of the temporality helps understanding the user's perspective to the experience. The evolution of cumulative (or long-term) UX and the phases included in it have been recently studied by, e.g., Karapanos et al. (2009). However, the discussion around this aspect is excluded from the scope of this thesis.

According to the discussion about *continuous engagement* and *sense making* by Wright et al. (2008), meaning is formed out of the interplay between the compositional, sensual, emotional, and spatio-temporal threads (presented in Section 2.3.2). This formation can be further divided into six processes that describe the human sense making and reflection. Temporally the processes follow each other but the time scale between them can vary and each process might not be present with every experience.

(1) *anticipating*: expecting the experience to offer certain possibilities for action or outcomes, as well as anticipating specific temporal and spatial character of it

(2) *connecting*: the immediate, prelinguistic sense of a situation, such as the immediate feeling of calmness when entering a web site. This has also been referred to as 'the emotional climate' and it shapes how one later interprets what is going on

(3) *interpreting*: "the process of finding narrative in the encounter, the agents and action possibilities, what has happened and what is likely to happen and how this relates to our desires, hopes, and fears and our previous experiences"

(4) *reflecting*: a form of inner recounting that takes beyond the immediate experience to consider it in the context of other experiences

(5) *recounting*: finding new possibilities, cultural and social meanings and points of relevance in the experience by recounting it to others

(6) *appropriating*: relating the experience to our sense of self, personal history, and hoped-for future

2.4 User Expectations and UX

According to the justifications in Chapter 1, UX should be investigated not only during or after the interaction but also before it. In fact, it can be interpreted that the ISO definition of UX draws a parallel between "the use" (i.e., the actual, felt) and "anticipated use" (i.e., the expected) of a system (ISO 2010), hence implying the salience of users' expectations of the UX. In addition, for example Karapanos et al. (2009) state that "often, anticipating our experiences with a product, becomes even more important, emotional, and memorable than the experiences per se". Because of the centrality of expectations in this thesis, the following aims at specifying their role and relation to UX.

The significance of expectations has been highlighted already in the first conceptual models describing the temporal nature of UX. Kankainen (2003) emphasizes that UX depends on the user's previous experiences as well as expectations towards the product (Figure 5). The current experience, in turn, modifies the user's expectations during the encounter, which creates a cyclic process of revising the expectations over time.

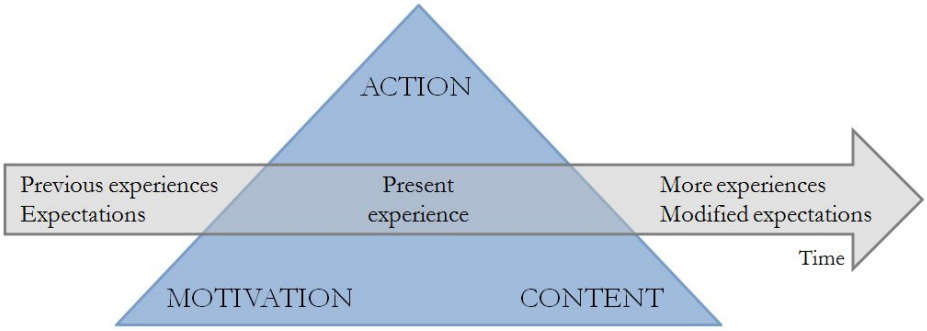

Figure 5. The temporal model of UX according to Kankainen (2003): the previous experiences and expectations affect the present experience, and this, in turn, modifies future expectations.

Wright et al. (2008) talk about *anticipation*, and consider it as one of the central human sense making processes: experience is always shaped by what has gone before. Baumeister et al. (2007) also argue that people anticipate consequences by reflecting on past and current experiences. Happening prior to any actual experience of use, the act of anticipating (or *expecting*) an experience is based on the prior events, encounters and interactions, and results in the formation of *expectations*. Similarly, Yogasara et al. (2011) use the term "anticipated user experience" (AUX), with which they mean "the experiences and feelings that the user *expects* to occur when imagining using an interactive product or system".

People's expectations and attitudes towards the future have been studied especially in economics and marketing research, for example, as measures of economical growth, customer satisfaction and loyalty, or as indicators to help forecasting stock exchange rates. For example, Teas (1993) distinguish between different *levels* of customer expectations, ranging from "desired service" in the highest end and "adequate service" in the lowest. Different levels on this dimension vary from "ideal expectations or desires" to "normative 'should' expectations", "experience-based norms", "acceptable expectations", and, in the lower end, "minimum tolerance expectations".

Considering the domain of HCI and UX, *users'* expectations could relate to the product or service itself, the use of it, or the experiential outcomes of the use. Wright et al. (2008) note that people may expect the experience to offer certain possibilities for action or outcome (e.g., what new activities does a product allow). In addition, the *temporal* and *spatial character* of the experience can also be anticipated to some extent – for example how strong would the experience be and for how long. The analysis by Yogasara et al. (2011) report that users' anticipations included various aspects related to the *context*, experiential *knowledge*, and anticipated *emotion*. Furthermore, Demir et al. (2009) argue that the expectations may be also about an unexplored aspect of a product (e.g., performance prior to usage) and about the consequence of an action (e.g., pushing a button to go to the menu of a cellular phone).

How do the expectations in fact influence the user experience? Wright et al. (2008) abstractly state that different expectations give different "shades of meaning" to the encounter with the product. Hiltunen et al. (2002) discuss expectations as the basis of the user experience cycle: expectations direct human interpretation and information gathering and attention in using the product. For example, a high expectation of a novel interaction technique in a product (e.g., touch screen in its early days) might interfere noticing other features or even using the product for its actual purposes. Arhippainen (2009) claims expectations to influence the user's perceptions of the product's capabilities and overall quality. According to the expectation confirmation theory by Bhattacherjee (2001), expectations exist as a norm against which the actual experience is compared. This general assumption was empirically corroborated by Raita and Oulasvirta (2011) who ran an experiment with 36 participants to see how product reviews affect subjective usability ratings. Those who had read a positive product review before the test gave the tested mobile device significantly better post-experiment ratings than the negative-prime and no-prime groups did.

Furthermore, if a product outperforms the expectations on important benefit dimensions, post-use satisfaction has been shown to result (Lindgaard & Dudek 2003, Oliver 1997), whereas if it falls short of expectations, the user is likely to be dissatisfied (Oliver 1977). Hence, in some situations people might adjust their expectations to avoid further disappointment (Wright et al. 2008). However, Karapanos et al. (2009) conclude that in product satisfaction judgments, the meaning of the expectations probably varies from case to case, and that people could also interpret that their expectations are unrealistic if not met. Hence, the actual experience with the product might become more dominant and the perceived importance of the aspect that did not meet the expectations might diminish as a result. Be that as it may, the process and precise effects of anticipation seems not be well understood with regard to the phenomenon of UX – a body of conceptual frameworks and hypothesis have been presented but relatively little empirical evidence has so far been reported.

With regard to the origins of the expectations, Dewey (1925) has identified social factors (e.g., others' opinions and experiences), traditions (e.g., norms, personal tendencies) and influence of education as sources of expectations. In consumer research, Zeithaml et al. (2002) mention the sources of expectations to consist of, for example, word-of-mouth, own past experience, personal needs, explicit service promises (personal and non-personal statements about the service made by the organization to customers) and implicit service promises (e.g., price, five-star ranking of a hotel).

Although the origin of the expectations is not in focus of this thesis, it is important to note that the expectations might not only depend on the experiences of the product, product type, or company in question, but also on other products – be they rival products or representing different product types – as well as on other people and their experiences and expectations.

Overall, these remarks above imply that also expectations can be multifaceted, be targeted to various aspects of the product use, and relate to various aspects already identified to relate to UX. Basing on the descriptions above, a central assumption in this work is that expectations can be attributed also to the *type of experience* – the diversity of which the earlier sections have profoundly described – that results from interaction with a service or product. However, the diversity of characteristics of expectations might not be as extensive as that of actual experiences: for example, it might be challenging to anticipate the overall experience cumulated over time, how the various contextual factors might influence the experience, or what the sensory experience from the interaction might feel like. Despite their salience, expectations of products or services have not been excessively studied in the field of UX or HCI in general. Expectations-based research approach can be fruitful also with products that do not exist yet – when there is a high risk of unsuccessful development investment and an extensive design space that would benefit from focusing. As noted by Yogasara et al. (2011), by understanding users' expected experiences that are positive by nature it can be easier to interpret what product characteristics could contribute to the experiences and how. Similarly, looking into the negative expected experiences can help identifying undesirable product attributes that prevent the users from having pleasant experiences.

2.5 Contrasting UX with Other Concepts Related to HCI

With its all-encompassing definitions, UX can be considered as an umbrella term that pulls together various similar concepts related to people's reactions to and relationships with technological systems, as well as the properties of products and services that create them. Examples of several-decade-old research areas that are now often understood as part of the scope of UX are cognitive ergonomics, human factors, affective computing, aesthetics and even usability. To further define the focus areas of UX, it is next contrasted with the concepts of usability, user acceptance and customer value.

Usability

Usability is a term denoting the extent to which a user can employ a product in order to achieve a specific goal (see, e.g., Norman 2002). The ISO 9241-11 (ISO 1998) defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". The foundations of UX lie largely in the traditions of usability. One of the first aspects that were considered as evidence in favour of establishing the concept of UX was the findings that perceived beauty strongly affects perceived usability (Tractinsky et al. 2000). Similarly, Blythe et al. (2003) introduced the concepts of fun and engagement in the scientific discourse about the need to extend the concept of usability.

Table 2 summarizes noteworthy differences between the often-transposed concepts of usability and UX (based on Desmet & Hekkert 2007, Hassenzahl et al. 2006, Hassenzahl & Ullrich 2007, Law & Schaik 2010). Overall, UX moves towards a more emotionally appealing relationship between the user and the product. UX is a necessary viewpoint especially when the interaction is not goal-oriented (e.g., informally learning to use a product, exploring the features of a product for fun, or other *casual interaction*). Hence, for UX the time spent on the interaction should not be considered as a scarce resource or the use of resources be balanced with the potential outcomes (e.g. achieving goals). Usability as a product quality is considered as a strongly contributing aspect in creating a good user experience, but "it is just one part of it" (Roto 2006). Furthermore, usability is often regarded as a "must-be quality", that is, an attribute that is taken for granted when fulfilled but result in dissatisfaction when not fulfilled, whereas UX can be seen as an "attractive quality", i.e., something that provides satisfaction when achieved but does not cause dissatisfaction when not fulfilled (terms from Kano et al. 1984). Similarly, Zhang and Dran (2000) discuss the same duality but use the terms "hygiene factors" and "motivators".

Table 2. Central differences between the concepts of Usability and User Experience.

Aspect	Usability	User experience
Refers mainly to	A product quality: products have properties that make them usable	Person's experiential outcome of interacting with the product
Scope	Efficiency and effectiveness of use and task completion	More comprehensive, covering also experiential and emotional aspects
Assessment	Objective (e.g., objective goodness of the product)	Subjective, based on the way people experience and judge products
Dynamics	Relatively persistent	Inherently dynamic
Goals	Do-goals	Be-goals
Design focus	Removing negative factors in design (e.g., problems, barriers, frustration, discomfort)	Creating positive outcomes of the interaction (e.g., stimulation, appeal, joy, excitement) and surpassing user expectations
	"Now it's no longer adequate just to avoid bad experiences, we have to find methods for designing good ones" (Blythe et al. 2003)	

User Acceptance

User acceptance (or 'technology acceptance') refers to the user's willingness (intention) to accept and put into use the available systems and services (Venkatesh et al. 2003). The original technology acceptance model (TAM) by Davis (1989) argues that user acceptance is mainly affected by *perceived ease of use* (free of effort) and *perceived usefulness* (enhanching one's job performance). Moore and Benbasat (1991) widen this coverage by presenting a set of measures for *relative advantage* ("the degree to which an innovation is perceived as being better than its precursor"), *compatibility* ("…perceived as being consistent with the existing values, needs, and past experience of potential adopters"), and *voluntariness of use* ("…use of the innovation is perceived as being voluntary, or of free will"). Additionally, Kaasinen (2005) suggests also the concept of *trust* to affect the acceptance, referring to perceived reliability of the technology, reliance on its service and the user's confidence of being in control.

To distinguish between UX and acceptance, acceptance incorporates mostly pragmatic aspects, such as perceived usefulness but, at the same time, it considers the person's values, past experiences and voluntariness, which can be seen to be inherent aspects in UX as well. Law and Schaik (2010) identify that "models of technology acceptance […] do not attempt to model individuals' actions on specific occasions, but instead focus on regularities in behaviour, consistent patterns of action, response tendencies". Hence, perhaps the main difference is that acceptance models often investigate technology adaptation from a societal level and with statistical methods, whereas UX focuses on the personal level and qualitative methods. Furthermore, the temporal perspective is different: acceptance focuses mostly on the initial adoption decision, whereas UX is interested in all the phases of product life cycle as well as how the experience evolves over time.

Customer Value

Another relevant concept, which has its origins in marketing and economy, is customer value. "[Customer] value is the consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given" (Zeithaml 1988). Furthermore, Holbrook (1996) emphasizes that customer value is comparative in that one must make utility comparisons among objects: "An interactive relativistic preference experience". Similarly as UX, the concept of customer value has been defined with different perspectives. Woodruff (1997) has identified areas of consensus within the theories, concluding the following: (1) customer value is "inherent in or linked through the use to some product", (2) it is something perceived by customers rather than objectively determined by sellers, and (3) it involves a trade-off between what is received (e.g., quality, benefits, worth, utilities) and what is given up to acquire and use the product (e.g., price, effort, sacrifices).

Drawing from these definitions, there seems to be several similarities between UX and customer value. For example, also customer value resides not in the purchase but rather in the subjective consumption experience(s) derived therefrom. Nevertheless, there are some differences, perhaps mostly originating from the disciplines that the concepts represent. First, customer value emphasizes the balance between effort and perceived benefits. Consequently, customer value considers the product's features more holistically, also incorporating, e.g., brand, price and other paid effort, which usually are not explicitly stated in the UX frameworks. Second, UX is more emotionally oriented (i.e., the psychological vs. product-centered orientations). Third, UX is interaction-focused, whereas customer value focuses more on the outcomes. However, the time span of *overall UX* can be seen as rather close to the concept of value in this regard. Fourth, value seems to be always consciously and rationally determined (a reasoned decision about the value). Finally, marketing as a discipline can be seen more interested in aspects related to promoting and selling products, whereas UX is interested in how the use affects the perceived value and how to design successful products.

All in all, the conceptual dissection above helps not only framing the scope of UX but also to understand the realms of user-centeredness more holistically. The different concepts can be used, for example, in analysis of empirical user research results. Specifically user acceptance and its established evaluation measures are utilized also in the empirical parts of this thesis (see Chapter 4).

2.6 Designing for and Evaluating User Experience

So far, much research effort has been directed to determining the ontologies or taxonomies of experiences in interaction with technology in general (e.g., characteristics and types, emotional components). However, because of the holisticity and conceptual richness resulting from different viewpoints, UX is often critiqued for being vague, elusive and ephemeral (Hassenzahl & Tractisky 2006). UX is associated with hard-to-quantify concepts, such as 'pleasure', and 'emotions', and is affected by broad concepts like culture and context. The broader extent of UX as a concept and especially the subjective and dynamic characteristics of experience have caused new methodological challenges for *designing and evaluating* UX. The UX field needs rooting the research – both empirically and theoretically – in specific areas or domains in order to focus the scope and allow building more relevant design and evaluation methods and heuristics (Ibid). Such areas could be, e.g., UX of mobile environments, UX of UbiComp, UX of social media, or UX of AR. This notion is also one of the premises of this thesis research. Consequently, this section aims to briefly introduce and further justify the practical targets of the thesis; that is, supporting design and evaluation of MAR services with design implications and evaluation measures that are relevant to the particularities of MAR.

Bargas-Avila and Hornbæk (2011) present an analysis of empirical studies around UX. They present the diversity of methods used in the studies (ranging from questionnaires and interviews to diaries, probes and psychophysiological measures) and the temporal aspects of UX assessment (before, during, and after use). One of their conclusions is that, despite the HCI field having adopted the new concept of UX, the methods and approaches used for UX research are much similar to those used in usability research, and the new methods that have been proposed are hardly validated or their reliability assessed. Overall, it can be said that the need for new *methods* is hardly valid (e.g., to replace interviewing, walkthrough methods or expert analysis methods). Rather, what really are needed are new guidelines and heuristics to facilitate designing for the experience as well as new measures and tools for evaluating the complex and dynamic experiential phenomena.

2.6.1 Designing for User Experience

Because of the comprehensive nature of UX, designing UX naturally needs to address its various facets. The foundation, however, is much similar as that of designing usability or user-centered design in general. The fundamental requirement for a good user experience is to meet the needs of the user. Similarly, the design needs to be multidisciplinary, involving, e.g., hardware engineering, marketing, industrial design and information architecture. Hence, also UX design should start from the concept level, before implementing any concrete demonstrators of the system (ISO 2010).

Nevertheless, designing for UX brings about also new challenges and aspects to consider. New terms, such as *emotional design*, *experience design* and *experience-driven design* have evolved accordingly. According to Hassenzahl (2011) "*Experience Design* stands for technology, which suggests meaningful, engaging, valuable, and aesthetically pleasing experiences in itself". Wright and McCarthy (2011) regard experience-centered design as a process that values the whole person behind the user and employs the *targeted experience* as a central concept in the design vision. In addition, the Nielsen

Norman Group[1] argues that "true user experience goes far beyond giving customers what they say they want, or providing checklist features." To summarize the chapter so far, designing for UX needs to consider all the human senses, creation of personal meaning, emotions, various levels and durations of engagement with the product, enjoyableness, the evolution of use, users' expectations etc. UX design not only addresses the *what* and *how* to do something with technology but it starts from the *why* – the fundamental human values and needs behind every activity (Hassenzahl 2011).

In other words, the focus in usage and perceived value shifts from the technology itself to what it means, what it makes possible, and how it feels. The designed system provides the instruments and affordances for activities, but it is the people who give it meaning and purpose. Forlizzi and Ford (2000) point out that designer trying to craft an experience can only design situations rather than predicted outcomes. Only the technology, interaction with it, and its content can be designed – not the subjective meanings, values and purposes of use, or the user's different cultural backgrounds, prior experiences and current emotional states. Consequently, no particular experience can be *guaranteed* by design. They can only be supported with technological premises to help the experience be evoked. Overall, this is the core of designing *for* experience: identifying the factors in the system or its intended context that can be designed or influenced with design (i.e., controlled), acknowledging the aspects in the wholeness that are beyond control, and reducing negative aspects that might prevent the positive emerging. Moreover, this is the very challenge that needs to be supported with empirical research knowledge of UX (e.g. delightful experiences) and new kinds of guidelines and considerations.

2.6.2 Evaluating and Modeling User Experience

Similarly as designing for UX, holistic evaluation of UX is challenging because of its dynamic, subjective, and hard-to-quantify nature. Accordingly, Vermeeren et al. (2010) point out that there are no widely accepted standard methods with which to evaluate UX. They gathered 96 methods that vary in terms of what is the source of the research data, what kind of data they allow to be gathered, in which phase of development they can be utilized, and what dimensions of the overall UX can be covered. This variation results from UX researchers having adopted methods from, e.g., marketing research, psychology, and interaction research, as well as from each evaluation case having particular approaches, contexts of use, target users, and interest areas within the UX spectrum (emotions, aesthetics, fun, flow etc.). In addition, UX is subjective: the criteria the user applies as a standard comparison depend on personal perception and prior experiences. Considering the above, it seems that no single method can be used for all cases or for a truly holistic evaluation.

An example of a rather well-known present evaluation method is AttrakDiff[2], a tool for evaluating the pragmatic and hedonic quality of products, consisting of semantic differentials scales with 28 evaluation items about the components of pragmatic quality, hedonic quality-stimulation, hedonic-identification, and attractiveness (examples: confusing – clearly structured, inventive – conventional). Another similar, which also has been validated to some extent, is the User Experience questionnaire

[1] www.nngroup.com/about/userexperience.html
[2] www.attrakdiff.de/en/Home/

by Laugwitz et al. (2008). These methods, among many others, are rather generic in the sense that they are intended for evaluating any type of products, and focus on identifying product attributes from a rather high level of abstraction. Furthermore, other methods include, e.g., attribute elicitation to compare product alternatives, psychometric measures like electroencephalography and facial expressions as well as subjective scales, such as PANAS[1], to measure different levels of emotional states, interviews and observations, experience sampling to gather subjective descriptions of the experience, and UX expert reviews to assess the product in terms of UX (Väänänen-Vainio-Mattila et al. 2008). The gamut of methods is indeed wide, which requires the user of the methods to have familiarity with them in order to achieve meaningful and valid evaluation results.

A central element behind the evaluation methods and especially quantitative measures are *models* that describe specific aspects of UX and/or their interactions. According to Law and Schaik (2010), measurement models enable UX to attain a certain level of validity, and allow identfying and operationalizing meaningful measures: "sound theoretical framework that defines the nature and properties of a (multidimensional) UX construct can inform its operationalisation and manifest measures". The evaluation of UX in general allows benchmarking solutions, and selecting and iterating the most appropriate design solutions (Law & Schaik 2010). In other words, to be able evaluate requires (1) first identifying meaningful concepts, (2) then building of constructs and goals to measure, and (3) only after that operationalizing the measures with which to actually perform the evaluation. Because of the complexity of UX, conceptual clarification is foremost before building any measures.

With regard to modeling, Law and Schaik (2010) highlight particular orientations that can – and should – be considered in creating structural models of UX. First, the time scale of human action can vary drastically, which can have profound effects on the content of the models. Second, the scope can vary from the experience of the interaction in detail (e.g., flows of action and sensory responses) to broader aspects of social cognition, such as technology acceptance. Third, orientation with respect to time varies as well: UX can be modeled as a state, at a particular point or interval in time, or as a process, involving the development of this experience over time (static models vs. dynamic models). Fourth, regarding cultural differences, the minds of people in different cultures have been programmed differently (Hofstede 2006), which can result in different conceptual structures and different relative qualities or strengths in different cultures. Overall, this implies that any model of UX should be contextualized to a specific context, time span, and types of experience.

2.7 Summary

Despite the challenge of crystallizing the core of the concept of UX, a few facets can be recapitulated here: its dynamic and subjective nature, its different characteristics (e.g., emotional, sensory, aesthetic, instrumental), and the different time spans (anticipated, momentary, episodic and cumulative UX). As a relatively new concept, there is no 'grand unified theory' that would cover the entire enormity of UX-related aspects. Rather, there is a collection of frameworks that each look into UX from slightly

[1] www.psychology.uiowa.edu/faculty/clark/panas-x.pdf

different perspectives (e.g., interaction-, product-, and user-centered frameworks), hence providing researchers and practitioners with an immensely rich library of insight into its nature and variability. Nevertheless, UX is an increasingly important quality attribute that has drawn much interest in creating new methods with which to evaluate it and design for UX. Having concepts and frameworks based on which to exchange knowledge, educate people, build hypotheses, and plan empirical research is crucial for the advancement of the field. Reciprocally, it is important also to carry out empirical research based on which to further refine the frameworks and methods.

User expectations are a central, yet little studied element of UX: expectations affect the user's perceptions of the product's (or service's) capabilities and quality, interaction with it, and the experiences it evokes. Expectations can be manifested on various levels: as user needs and desires, or as requirements and presumptions. Regarding emerging technologies, there is very little understanding of what the expectations of such are and based on what aspects are the expectations built on. Nevertheless, it has been argued that UX should be taken into account already in the beginning of product development by empirically researching people's expectations. A fundamental premise of this research is that by understanding users' expectations it is easier to outline products and services, target to specific experiences in the design, and to envision how the product or service characteristics could contribute to the UX.

3. Mobile Augmented Reality

Augmented reality (AR) is a field that intertwines various topical technologies and emerging concepts. AR is a multifaceted term that can refer to (1) a technology or a group of technologies – a mesh-technology that utilizes also several other technologies, (2) a concept that describes a vision of future computing, (3) a field of research in various disciplines, (4) a medium and an interface to digital information, and (5) recently also a platform for creating novel services and business. Consequently, this chapter presents AR from various viewpoints, starting with a description of the concept of AR in general and its relation to concepts like mixed reality and ubiquitous computing. This is followed by descriptions of *mobile augmented reality* (MAR) as a special instance of AR. Various elements and technologies behind MAR and the application areas in which MAR is applied are desribed. Finally, an overview on the user research conducted in related areas is presented.

3.1 Introduction to Augmented Reality

Before looking into the technical definitions and visions of AR it is enlightening to analyse the two words it is comprised of: *reality* and *augmentation*. First, there are various philosophies about the concept of reality, for example taking perspectives on religious or metaphysical aspects. Because of this conceptual diversity, the following focuses on the physical and objective reality that we are able to sense around us. Merriam-Webster[1] offers several definitions for *reality*, for example the following:

> "A real event, entity, or state of affairs: the totality of real things and events"
>
> "Something that is neither derivative nor dependent but exists necessarily"

These imply that reality includes, for example, the physical things like nature, places and people, the actual and conceptual structures like biological organisms or human language, and events and phenomena like the laws of physics or a laughter of a child. The Oxford English Dictionary[2] emphasizes that reality is the state of things as they actually exist, rather than an idealistic or notional idea of them (e.g., how they are imagined). Hence, reality can be contrasted with what is imaginary, dream, false, artificial or fictional. The *truth* refers to what is real and *falsity* to what is not.

Second, to augment is defined in Merriam-Webster[3] as:

> "To make greater, more numerous, larger, or more intense"

This can be understood in many ways: the aspect of the objects of reality that are augmented can relate to their physical characteristics, their actions, their meanings and the concept itself. Consequently, literally augmenting reality provides an endless breadth that needs to be narrowed down for the purposes of using the concept in information technology.

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[1] Merriam-Webster encyclopedia: www.merriam-webster.com/dictionary/reality, Accessed 20.3.2012
[2] Compact Oxford English Dictionary of Current English. Oxford University Press.
[3] Merriam-Webster encyclopedia: www.merriam-webster.com/dictionary/augmenting, Accessed 20.3.2012

In relation to computer science, the term "augmented reality" was first used by Caudell and Mizell (1992) in Boeing Corporation to refer to overlaying computer-presented material on top of the real world in helping aircraft assembly tasks. Their approach is still the fundamental idea behind augmented reality: to superimpose digital (computer-generated) content like graphics, audio and other sensory enhancements over the perceptions of the real-world environment in real time so that they appear as one reality (see, e.g., Mackay 1996, Vallino 1998). In other words, the physical reality becomes enriched with falsity (i.e., artificial and fictional information) that originally was not counted as reality, and the user might not even notice that the augmentation has taken place.

In the widely accepted definition of AR as a computer science concept (Azuma 1997), three requirements for AR are emphasized:

(1) the combination of real and virtual imagery
(2) the alignment of computer graphics with objects or locations in the real 3D environment
(3) interactivity and in being real time

Following these requirements, AR is often manifested as a visual interface where digital imagery is aligned on the view of the real world. The physical world around us provides a wealth of information that would be difficult to duplicate in a computer. The various elements of reality, such as people, places and things, can be seen as affordances for AR; that is, they are the objects that are augmented and may provide the viewer of the AR interface with interactivity. Other sensory modalities can also be used to augment the reality (e.g., auditive AR where the perceived audio environment is supplemented with digital sounds, or even haptic AR), which, however, are not in the focus of this thesis. Either way, AR can enhance users' performance in and perception of the world (Vallino 1998).

3.1.1 AR, Mixed Reality and the Other Reality Concepts

Augmented reality is a part of a broader concept of *Mixed Reality* (MR). MR refers to the overall integration and complementation of the real and virtual, through which new mixed spaces or realms are created (Milgram & Kishino 1994). MR creates an intersection where real and virtual-world objects are presented together in a single experience (Schnabel 2006). Figure 6 presents the mixed reality continuum accompanied with other related "reality concepts" as discussed by Schnabel et al. (2007).

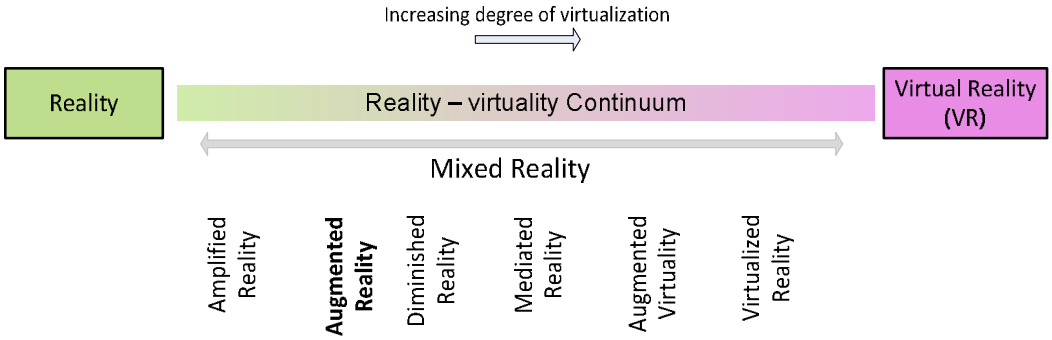

Figure 6. The Reality-Virtuality Continuum and the approximate relation of AR and other relevant concepts to the level of virtuality and reality. Adapted from Milgram and Kishino (1994) and Schnabel et al. (2007).

In the virtual end of the continuum, *Virtual Reality* (VR) is defined as a computer generated, interactive, three-dimensional environment in which a person is immersed (Rheingold 1991). Next, *Virtualized Reality* virtualizes real visual scenes by capturing them from a number of angles, thus creating a 3D structure of the scene, such as a photo-based 3D model of a city (Kanade et al. 1995). *Augmented Virtuality* (AV) means the augmentation of a virtual setting with real objects and allows merging a richly layered, multi-modal, 3D real experience into a VR (Milgram & Colquhoun 1999). Getting closer to the reality, *Mediated Reality* refers to artificial modification of human perception in general, including both augmentation and diminishing. *Diminished Reality* removes physical objects by replacing them with an appropriate background image (Lepetit & Berger 2001). It can be seen as an opposite to AR as it extracts information from the reality. Finally, Falk et al. (1999) introduced the concept of *Amplified Reality* to complement AR, meaning enriching the properties of physical objects with the help of computation. Schnabel et al. (2007) point out that AR overlays virtual properties onto elements, however not altering the tangible object itself but rather the perception of it, while elements within an amplified reality include their proprietary rights to them.

Overall, different concepts represent slightly different levels of abstraction or can be considered as specific manifestations or facets of other concepts. The first three instances (VR – AV) in Figure 6 are completely or mostly computer-generated environments that replace or stand in for the reality. AR, on the contrary, maintains the primacy of the real world and adds digital enhancements to it.

Along with the continuum, also the level of digital modelling (or "extent of world knowledge" by Milgram & Kishino 1994) varies accordingly. On the left-most extreme of Figure 6, the world is poorly modelled (i.e., 'computerized') and the exact place of an augmentation is not known, which produces AR that is crude and unrealistic. On the other end, all the content and their places are well known as the world is completely computerized, such as in digital game environments. Furthermore, when focusing on the AR part of the continuum, the level of realism varies in different types of augmentations. Abstract augmentations consist of, for example, text, indicators, 2D image or inserted video simply overlaid on the real world, whereas 3D wireframes or objects with precise alignment create more realistic augmentations (Wang & Dunston 2009). The more realistic the augmentation, the less cognitive load is required to interpret the virtual information but with higher computational costs.

Overall, regardless of the level of realism or extent of world knowledge, AR allows construction of appropriate systems that enable tangible interactivity, convey extra information about the environment, and thus enhance our daily activities (Wellner et al. 1993). AR content adds another layer to the experience of reality, which can produce new meanings and interpretations. This means that the reality that is augmented is not solely physical, but also conceptual (Barba et al. 2010).

3.1.2 AR in Relation to Ubiquitous Computing

Weiser (1991) conceptualized ubiquitous computing (Ubicomp) as an environment where computing technology is embedded into various everyday objects, such as physical appliances or furniture. This would result in computing disappearing into the background and becoming transparent to the user (often referred as *Pervasive Computing*). Over the two last decades, however, the concept has strongly

expanded, and nowadays it is often considered as an umbrella term for various related concepts – with regard to both the visions of future and the technologies making it possible. Consequently, AR can be considered as an important technological development trend that relates closely to Ubicomp. The following opens up various aspects that, in my opinion, not only characterize the intricate concept of Ubicomp but also illustrate how augmented reality relates to these aspects.

First, using sensor technologies allows technological systems to sense and perceive the surrounding world, for example, with the help of *computer vision*, which is apparent also in AR. AR is as much about reading the surroundings as it is about adding things to it. This aspect of AR relates to, for example, *context-awareness* and *location-awareness* that allow for location-based services (LBS) and adaptation to the user's context (see, e.g., Loke 2006, Henrysson & Ollila 2004). Dey (2001) defines context awareness: "a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task." Context-aware services can be characterized as 'ad hoc', meaning that the use of technology is based on the user's transient needs and other momentary appraisals related to the current moment and context of use.

Second, digital information is becoming embedded in the everyday things in the reality, such as products, places, objects, and people. AR can serve as an interface to this ubiquitous information, for example, with the help of the aforementioned sensor technologies and identification of the things in the reality. This aspect relates to the concepts of *smart environments* and *internet of things* (IoT) that emphasize that objects themselves including digital information can create 'smart' services and novel interfaces (Atzori et al. 2010).

Third, operating, reacting to and controlling the Ubicomp technology often intend to mimic *embodied* interactions that are familiar from the interactions with other people and the physical world (Dourish 2001). AR can be considered as a *tangible* user interface (TUI) (Ishii & Ullmer 1997), for example because it utilizes the metaphors of natural body movements to change the point of view of the AR. Furthermore, visions of realistic AR involve mimicing the real world: objects look like and act like real things, and they might even allow interaction with direct manipulation (cf. Fishkin 2004).

Finally, in various everyday situations, utilizing proactive and automatic system functionalities can be very useful for the user: for example, automatically reacting to the user's actions and the current environment by offering contextually relevant information. With the holistic visual AR interface, such proactivity can ease finding the most relevant information and provide ad hoc services. This relates to the concepts of *Ambient Intelligence* (AmI) (see, e.g., Remagnino & Foresti 2005) and context-awareness.

All in all, in addition to mixing the reality with virtual, AR can be considered as a promising tangible interface to the various facets of Ubicomp. For example, Papagiannakis et al. (2008) see especially mobile AR as the meeting point between AR, ubiquitous computing and wearable technologies like wearable computers and displays. Billinghurst et al. (2009) envision AR and AmI to merge in context-aware ambient AR applications that allow users to easily perceive and interact with ambient information through the AR overlay. They furthermore conceptualize "tangible AR" as an interface where each virtual object is registered to a physical object and the user interacts with virtual imagery objects by manipulating the corresponding tangible objects.

3.1.3 Augmented Reality Is Becoming Increasingly Mobile

As a result of the rapid advancement of mobile devices, AR is entering also the mobile domain. One of the first demonstrators of MAR from already a decade ago was an indoor AR guidance system running on a personal digital assistant by Wagner and Schmalstieg (2003). After this, smart phones have been equipped with integrated cameras, sensor technologies like GPS and orientation sensors, high-resolution full color displays, highspeed networking, high computing power, dedicated 3D graphics chips etc. For example with regard to the sensor technology, smart phones can serve as external eyes and ears for sensing embedded information in the surrounding environment. Such a plethora of possibilities being integrated in one device that is extensively spread provide a dexterous platform for building AR applications and services (Wagner & Schmalstieg 2009, Henrysson 2007).

However, mobile AR is not only about having a mobile or hand-held device as hardware. It is about AR being enabled for truly mobile and ubiquitous contexts and activities – instead of the use being tied to stationary locations and carefully conditioned environments, such as in medical or manufacturing applications of AR (Höllerer & Feiner 2004). Mobile contexts and activities with AR could include, e.g., information search 'in the wild', wayfinding, choice of services and products, social interaction, entertainment and exploration of larger areas (see, e.g., Nilsson 2010; the application areas are described in more detail in Section 3.3.1). Additionally, for example military applications and maintenance could utilize both mobile and stationary AR. Overall, the mobile context is constantly changing as the user's physical or social environment, activities, or mental states change, which also affects the user's needs for interaction and task execution. Related to MAR, the term *handheld* AR refers to AR with handheld devices, whereas MAR can include also other mobile hardware.

Mobile AR has recently gained huge public interest. For example, the buzz around MAR in various blogs, Internet magazines and technology reviews has been simply outrageous over the last few years. MAR is expected to drive business in almost any area in which it would be utilized. Juniper research (2009) has forecasted AR to generate $732 million by 2014, consisting primarily of mobile apps and advertising. Similarly, Gartner (2009) has predicted context-aware computing to create a $12 billion market by 2012. These can be seen to correspond with the apparent potential of MAR truly publicizing Ubicomp. Especially a visual and accurate 3D interface to the surrounding digital information has been expected to engender a novel paradigmatic interface and offer a fruitful platform for ubiquitous mixed reality services.

3.2 Building Blocks of Mobile Augmented Reality

When considering mobile AR as a holistic service, one can identify various elements that it is constructed of (1) the underlying hardware and software technologies as the computational platform that provide the functionalities to acquire, store, manage and align digital content in order to create a mixed reality, (2) the digital content (e.g., 2D or 3D graphics, point-of-interest information) and the sources of it, and (3) the way of interacting with MAR to allow user input and, for example, selection of objects (Höllerer & Feiner 2004).

The following describes the above-mentioned aspects and discusses their role in the service wholeness. As a technological platform mobile AR exist at the intersection of research areas like computer graphics, computer vision, sensors and sensor fusion, display technologies, location-based information systems, personal area networks and wearable technologies. Because of the user-centered approach in this thesis, however, the review of AR-related technologies remains rather cursory. Instead, the following focuses on the interaction with the most prominent MAR technologies and their possible influences on the UX. More profound technical analyses are those by Azuma et al. (2001) and Papagiannis et al. (2008) who present extensive surveys on MAR hardware, networking solutions, tracking and registration, displays, wearable input, and interaction techniques in MAR. In addition, a collective web site[1] delineates the history of MAR especially from a technical perspective.

3.2.1 Tracking and Registration

Mobile AR utilizes various sensors to create a picture of the surroundings and to infer what digital content relates to the current context. To be able to accurately overlay digital information, the real-world objects and the user's location need to be *tracked* in real time to know the position and orientation of the system display in a physical coordinate system with known mapping to a virtual one (Papagiannakis et al. 2008). Without this, it is difficult to trick the human senses into believing that computer-generated virtual objects co-exist in the same space as the real objects.

There are several tracking methods, varying from large-scale solutions based on GPS, GSM or wireless-LAN to more accurate ones based on magnetic fields, intertial solutions (accelerometers and gyroscopes), sensors (e.g., radio frequency identification), visual markers or markerless tracking. For example, GPS is useful for aligning the AR content over long-distances, but often too inaccurate in short distances (<50m) (Thomas et al. 2002). Visual marker-based tracking requires fiducials, that is, easily recognizable landmarks, patterns or figures placed in known positions in the environment (e.g., printed markers, such as the well-known 2D matrix markers presented already by Rekimoto (1996)). Visual markerless tracking is based on different approaches of computer vision (Sonka et al. 2008) (e.g., natural feature detection, edge detection, planar methods) but requires high processing power. The different solutions can more or less be used in any kind of environments but there is variation in the achieved accuracy and range of use. With the help of such technologies, the AR system can infer, for example, the user's location, what she is looking at, and to where and how fast she is moving.

Tracking as such is hardly useful for real time AR without *registration*, that is, the final alignment of real and virtual information that is presented to the user (Henrysson 2007). The motions or changes made by the user need to result in the appropriate changes in the perceived virtual elements (Azuma 1993). To achieve a realistic interface and preserve the illusion of real and virtual coexisting in the same domain, registration must be made with pixel accuracy at high frame rates. Current state of the art in registration includes signal processing solutions for face detection, identifying moving objects in videos and continuous detection of specific visual patterns that have been identified in advance (e.g., patterns on packaging, products, clothing, artwork) (Mullen 2011).

[1] www.icg.tugraz.at/~daniel/HistoryOfMobileAR/

3.2.2 Displays as Output Technology

The first mixed reality displays date back to 1966 when Ivan Sutherland invented the head-mounted display and later created the first augmented reality system (Sutherland 1968). AR displays in general and their technical requirements and restrictions are discussed in detail in, for example, Azuma (1997) and Vallino (1998). To give an overview on the topic, the current variety of displays useful for MAR contain mobile devices as monitors, head-mounted displays, and either hand-held or head-mounted projection-based displays (Wang & Dunston 2009).

First, mobile devices like smartphones or tablet computers as monitor-based hand-held AR displays are often referred as 'window-on-the-world'. They are digital camera and video -based see-through screens and display visual augmentations of the reality seen through the screen in real time (Bimber & Raskar 2006). The field of view (FOV) is limited, depending on the monitor size, spatial alignment and distance relative to the observer. Thus, they can be considered as exocentric (i.e., provide a remote, non-self-centered view on the reality) as well as non-orthoscopic (i.e., distorted relative to the real scene) (Wang & Dunston 2009). Furthermore, as the reality is recorded with a single camera, the view to the 3D reality is monocular and projected on the 2D display.

Second, Head-mounted displays (HMD) provide a comprehensive and wide-angle view into AR, thus limiting the normal vision as little as possible. The solutions vary from the so-called data glasses[1] to near-eye displays (NED) and contact lens solutions in which the display is right up against the eyes of the user (Azuma 1997, Bimber & Raskar 2006). Data glasses are often based on video see-through where the visual field is recorded with one or two cameras (mono- or binocular). This more or less real-time video stream that can be supplemented with augmentations for the user. The latter two are based on optical see-through where at least partially transparent displays allow superimposing digital graphics on the optical layer itself. HMDs are generally a fruitful solution in terms of rich interaction: the user's hands are free for other activities or, e.g., giving system input and their entire field of view can be augmented at all times. The view to the AR is more or less egocentric (self-centered) and in real time and orthoscopic (Wang & Dunston 2009).

Third, projection-based displays use the real world surfaces to project visual augmentations on them ('spatial AR' or 'tangible media'; Mistry & Maes 2009). There are for example front-projection devices and head-mounted projection devices that approach to match the center of projection with the user's viewpoint, which makes them always appear optically undistorted. Projection-based AR is egocentric, orthoscopic and provides a direct view on the real environment – also for several people to view simultaneously (Wang & Dunston 2009).

Finally, a central computing task related to displaying AR information is *rendering*, i.e., the software process of generating an image from a digital model and credibly replicating its visual qualities. State-of-the-art solutions consider aspects like photorealism and appropriate lighting of the rendered object based on the surrounding conditions; for example, shadows or different transparency and reflections

[1] membercentral.aaas.org/blogs/qualia/data-glasses-next-big-thing-human-computer-interaction

of objects (Aittala 2010). In addition to the display hardware, also software solutions like this have a great influence on the user's sense of realism and immersion of the AR environment.

3.2.3 Content of MAR

The digital information content shown in MAR can relate to and augment anything in the user's current context, for example physical structures, places, things in nature, moving things like products and people, and also intangible and abstract things like services and events. The content varies in form, consisting of, for example, 3D multimedia content, 2D graphics, animated graphics, frames highlighting objects or their shapes (e.g., corners, planes) in the reality, simple textual information and graphical symbols. Wither et al. (2009) refer to content as *annotations*: "additions of extra virtual information to an object". The various annotations can, for example, simply provide a name of the object in reality, describe its characteristics (e.g. availability of a service), add new virtual objects to the scene (e.g. virtual characters), modify the real objects (e.g., change surface colour or luminosity), or direct the user with arrows and other highlights (Wither et al. 2009). In other words, AR content can be added either directly about a particular real world object or shown in a more indirect or abstract way. Furthermore, the semantic relevance and permanence of the annotation depends on the user's task, her interactions, and changes in the virtual elements of AR.

The origin and storage place of the content can naturally be the local device (e.g., 3D models stored in device memory) or, currently more common, various online repositories to access with a network connection. MAR is a fruitful interface for exposing large amounts of visual content from existing online services like Wikipedia and content sharing services like Flickr[1]. With the development and openness of "network societies" (Castells 2000), for example map and multimedia repositories are being democratized by public authorities. In addition to this, people are increasingly relying on user-generated information from, e.g., social media (O'Connor 2008). Mobile AR can bring down all the resources of the Internet's cyberspace into the mixed reality, making the Internet ubiquitous.

A large portion of this Internet-based content is geo-tagged or otherwise bound to a location, which has made location-based MAR a rapidly growing area. Especially user-created geotagged content has become increasingly common thanks to online maps with user-created point-of-interest (POI) information, and online services built around maps (e.g. Yelp[2]). The location-based content can be efficiently related to the real world – both technically and mentally. The location information ties the situation in a certain space and helps delimiting what content to show on the AR interface.

3.2.4 Characteristics of Interaction with MAR

The overall metaphors of MAR, the various input and output technologies as well as the type of content have influence on the way of interacting with the MAR and what kind of experiences it can evoke. For example, the feeling of authenticity and immersion depends on the display and other output technologies as well as the authenticity and proper registration of the content. On the other

[1] www.flickr.com
[2] www.yelp.com

hand, one can consider the world and its information as the main platform and AR merely as an interface (or medium) to it. This section wraps up MAR from the viewpoint to the human-technology interaction and reflects on how the technical aspects affect it.

To reconsider output interaction devices, Milgram and Kishino (1994) provide two dimensions based on which to categorize the *realism* in AR/MR display output. First, the *reproduction fidelity* refers to image quality aspects like resolution, use of dimensions, shading, textures, and animations. With current technology, a very high level of realism can be achieved with any type of display. Second, the extent of *presence metaphor* describes the extent to which the observer is intended to feel present within the displayed scene. In this dimension, displays can vary from monoscopic imaging like single monitors to panoramic imaging (e.g. large screens and HMDs), surrogate traveling (i.e., the ability to move about within the world being viewed) and real time imaging.

Concerning input, Wang and Dunston (2009) present an AR input continuum. It extends in level of intuitivity from 2D-based input like a mouse cursor and 2D imitated controller input to more and more intuitive: from hand-held free space input to gestural input, tangible input (Billinghurst, Kato & Myojin 2009), and, finally, embodied input. Usually, the more intuitive the input technology, the less cognitive load is required – however, with the drawback of increased computational cost.

Considering the above, realism and intuitivity are clearly important targets in MAR. To continue discussing various aspects in the earlier sections, the following summarizes what is particular to interacting with the focus technology in this thesis – i.e., handheld video-see-through MAR:

- Compared to desktop or other mobile technology use, the interaction moves towards *context-based* use where the service of the technology depends on the surrounding information and the user's activities. MAR can be seen as a local search engine to the information embedded in the environment.
- MAR provides a *tangible* interaction metaphor for utilizing the realms of digital information. It can be referred to as "physical browsing" (Kindberg 2002), and thus can be considered pervasive and visually comprehensive as an interface. MAR interface can be seen to represent "full embodiment" (Fishkin 2004): the output device is the input device and the user can have the illusion of the system state being inside the object that is manipulated. Contrasting to projection-based MAR the difference is that the input and output are physically separated.
- MAR is a *lens-based* UI: it provides an inherently limited display size as well as a limited field of view (window to the AR, Milgram & Kishino 1994). Changing the direction of the view is based on hand movements rather than head movement as in controlling the FoV of human vision (Papagiannakis et al. 2008).
- Related to the previous, the view is *ego-centered*, i.e., a first-person view. This, along with the pervasiveness, affords a great degree of short-range local awareness but, on the other hand, not as high an awareness of the more distant surroundings as in map interfaces.
- Because of the browsing-oriented interaction, it might not have a clear beginning or end. Rather, the interaction can be continuous, consist of intermittent activities, and have multiple activities concurrently operating.

- With regard to physical interaction, it usually reserves one hand to hold the device and much attention to viewing the MAR screen. The input techniques with current devices are limited.

For a broader picture, Figure 7 reflects AR to specific well-known interface types that can be seen as prior interfaces for accessing and browsing digital information. Map interfaces refer to 2D representations of physical areas from above (possibly with POIs), 2D AR refers to ego-centered AR where tracking is based on GPS and magnetometers and simple 2D augmentations are visualized, and 3D AR refers to augmentations being 3D and precisely aligned. The figure summarizes the physical scale of interaction in relation to each of the interfaces and how various aspects change along this continuum. When moving from traditional WWW towards 3D AR, the integration of realities and reproduction fidelity grow, and the precision of the augmentations increases. Accordingly, there is an increase in the contextuality and relevance of the accessed information content and the user's sense of presence in the reality that the interface displays.

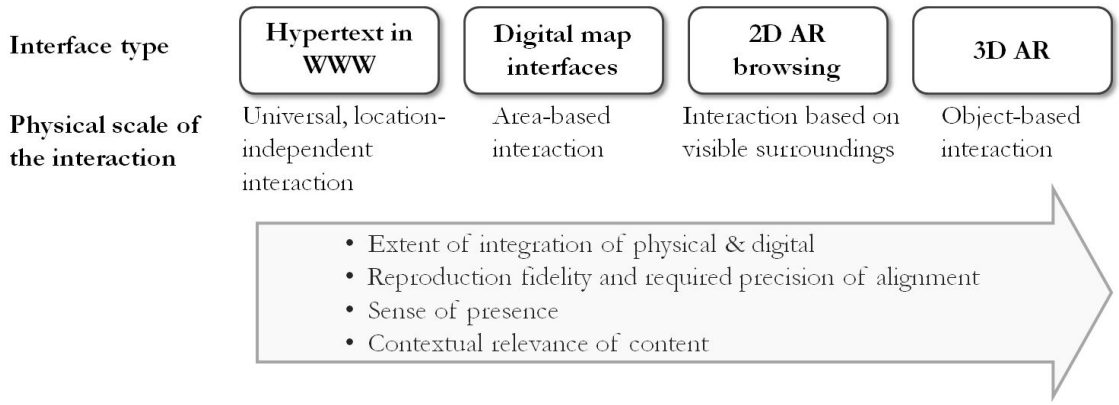

Figure 7. AR in a continuum of interfaces for accessing digital information.

Overall, because of the particularities in the novel way of interacting with AR, and the probable changes in the user's experience, there is a need to conduct research on the specific interaction techniques and experiences of interacting with handheld MAR (Henrysson et al. 2007).

3.3 Mobile Augmented Reality in Different Application Areas

Mobile AR has been experimented and demonstrated in various application areas and fields of research. Already in late '90s, Vallino (1998) listed a large variety of different areas for AR in his thesis, ranging from medical, military, engineering design, robotics, manufacturing, maintenance and other utility-oriented areas to consumer services and entertainment. More lately, the focus has changed from "AR as technology" to "AR as a medium" (MacIntyre et al. 2004) and the researchers have started exploring more experiential AR domains. What is more, recently the publicly available consumer-targeted MAR applications have gained much public interest as the first widely known embodiments of AR. The following two sections give an overview on the diversity of application areas where MAR has been (1) demonstrated and experimented mostly for research targets, and (2) commercialized with consumer-targeted first-generation applications over the last few years.

3.3.1 The Diversity of Demonstrators of AR and MAR Demonstrators

Numerous publications summarize different types of AR or mobile AR system demonstrators, prototypes or proof-of-concepts developed for research purposes in various application areas (e.g., Wither et al. 2009, Nilsson 2010, Höllerer & Feiner 2004). Characteristic to these systems are that they are seldom based on user needs and requirements, and thus remain in the research community, seemingly far away from the potential end users (Nilsson 2010). Nevertheless, these are heralds of future MAR services that would be truly useful for the consumers. For exemplification, the following list roughly categorizes the application areas and cites to a few exemplary publications and systems in each area.

- For several decades, the focus has been on industrial AR applications and work-related contexts. This has included, e.g., operating, maintaining, inspecting and repairing machinery (e.g., superimposing instructional information; Platonov et al. 2006), manufacturing, assembly and construction (e.g., Baillot et al. 2001), military applications like HMD-based systems for augmenting a battlefield scene and its infrastructure (e.g., Julier et al. 2000), and medical AR applications for image guided surgery helping to view the internal anatomy.
- Related to industrial areas with MAR, modeling and design fields have included, e.g., urban planning and architecture to visualize models of planned buildings (Allen et al. 2011, Olsson et al. 2012), as well as in virtual modeling, form-shaping and prototyping products.
- Entertainment and leisure-time-directed MAR systems have included using the real-world view as a background for gaming (e.g., 'human pacman' by Cheok et al. (2004) and ARQuake by Thomas et al. (2002)), adding virtual enhancements by 'painting on the canvas of reality', and bringing comments from social online services into the real world objects.
- Commercial AR applications have included aspects like providing additional information about viewed products, adding moving elements and social content to paper advertizing campaigns, virtual storytelling in tourism (Dow et al. 2005), trying out clothing (e.g., Ray-Ban[1]) and instructing of how to use products.
- Collaborative AR has been researched relatively much (e.g., Billinghurst & Kato 2002). This has included tele-conferencing, mediated social interaction, augmented identifications (e.g., augmented ID[2]), and team work in general. In this domain, also audio AR has been utilized together with synesthetic visualizations in audio conferencing (White & Feiner 2011).
- Finally, various utilitarian AR demonstrators have been utilized in, e.g., task support by acquiring context-specific information, furnishing gadgets (posters, fliers, billboards etc.), navigation and path finding (Feiner et al. 1997), education, translation, document verification, and using "X-ray vision" to see behind objects (Bane & Höllerer 2004).

All in all, the variety implies that (mobile) AR as a technology has been actively explored in order to test the technical solutions and develop them for specific targets. Another research target has been

[1] http://www.ray-ban.com/usa/science/virtual-mirror
[2] http://www.mobileaugmentedreality.info/augmented-id-iphone-application/

to identify the application areas in which (mobile) AR can provide real value and the current technical limitations, such as imprecision of alignment, do not create too much disadvantage.

3.3.2 The First Generation of Publicly Available MAR-Related Applications

Recently, we have witnessed a rapid proliferation of publicly available consumer-targeted mobile applications that utilize AR features. These can be considered no longer as demonstrators or proof-of-concepts but as full-fledged stand-alone applications that provide a relatively wide array of MAR-related functionalities. In this thesis, such are referred as *first-generation MAR applications*. They exhibit especially location-tied content aligned on the mobile camera view and simple interactivity with it.

A central background for the proliferation is online Apps Stores having become the primary distribution channel for launching new applications. In May 2012, there were over 1000 applications in the Android Market place and 380 smart phone applications in the Apple Store that result with the search term 'augmented reality'. Not all of them can be considered as true AR but the numbers nevertheless hint the magnitude.

The majority of first-generation MAR applications represent two common approaches: visual *MAR browsers* (Jackson et al. 2011) and *image recognition -based MAR* applications. Other types of applications include, for example, simple camera-based 'HUD's that show location and orientation info, navigation and transportation utilities (e.g., car locators, visual navigation, nearest tube[1]), and satellite, airplane and star trackers that highlight and describe very distant objects (e.g. Star Chart[2]).

A predominant interaction metaphor in the MAR browsers is the "magic lens" (Azuma 1993) with which the AR is explored through the camera view. Most often, this involves visualizing user-created POI based on the GPS location and magnetometer orientation. The idea of visualizing location based POIs was presented already by, for example, Feiner et al. (1997) who envisioned the "touring machine", i.e., an AR system for exploring the urban environment and providing textual AR information about the objects in the FoV. At that time, the systems were hardly mobile or handheld but the fundamental ideas represent those of today. Kooper and MacIntyre (2003) created the RWWW Browser, the first AR browser of the WWW. Only in 2008 was the technology mature enough to create a mobile phone based version (Wikitude[3]) instead of a cumbersome HMD system.

In addition to Wikitude, good examples of AR browsers of today are Layar[4], Junaio[5], Mixare[6] and Acrossair[7]. They all utilize MAR to draw geo-referenced data about, e.g., restaurants, services, places of interest, people's location, and from a variety of online services, such as Wikipedia, Panoramio[8], Yelp and Foursquare[9], to provide information on the user's surroundings and augment the location context with relevant data (see Figure 8 for examples). Typical use cases include information seeking

[1] www.acrossair.com/apps_nearesttube.htm
[2] www.appbrain.com/app/star-chart/com.escapistgames.starchart
[3] www.wikitude.com
[4] www.layar.com
[5] www.junaio.com
[6] www.mixare.org
[7] www.acrossair.com
[8] www.panoramio.com
[9] foursquare.com/

(querying the physical world), navigation, on-the-spot content recommendation and advertising, and provision of details about objects and places. Furthermore, many such applications are being transmuted into software platforms that allow bringing new types of content to be browsed (Madden 2011).

Figure 8. Screenshots from AR browsers. Left: nearby restaurants shown on Layar, Right: web cam feeds within nearest 15km shown on Junaio.

Image recognition-based AR utilizes visual recognition of QR codes, bar codes or other fiducials to identify surrounding objects. Especially such applications can be seen as a pervasive interface to Internet of Things as they provide a 'visual hyperlink' to information related to the identified object. Product-related applications like ShopSavvy[1] and StickyBits[2] are rather numerous in this area but Google Goggles[3] as a general image-based search application is one of the best known (Figure 9).

Figure 9. Screen capture from Google Goggles: first identifying a product and then using it as a search key in google search.

Despite the technical differences between the two main approaches, from the user's perspective there are many similarities in the first-generation MAR applications:

(1) the tangible and real-world referenced interaction
(2) visual augmentation of the physical world in more or less real time
(3) digital content related to locations or objects becomes more easily accessible
(4) the augmented content is somewhat interactive as it provides hyperlinks to online content

[1] shopsavvy.com/
[2] www.stickybits.com/
[3] www.google.com/mobile/goggles/

The first-generation MAR applications do not technically implement all the visions of AR. As discussed in Paper **IV**, the content is not truly 3D, the registration of content is rather imprecise (most often based on GPS), and the user is often a rather passive recipient of information with very limited ability to manipulate or create the virtual content in real time (lack of interactivity). Nevertheless, they are the first publicly available applications that utilize most elements of visual MAR, and thus can be expected to provide people with interesting experiences related to the novel interaction, new functionalities and the location- and object-based content. The applications can be seen visually captivating, to have a wow-factor due to the novelties, and to be able to visualize the invisible surrounding content that has been hard to access before. On the other hand, it is interesting to see how people interpret them and find meaningful uses for them. After all, Sá and Carriço (2008) identify that central user-centered challenges in new mobile technologies are that people might be unclear about the long-term value of the applications beyond the immediate entertainment and 'wow' factor.

3.4 User Research of AR and Related Technologies

Although some of the demonstrators and especially the applications listed in Section 3.3.2 are clearly designed with an end user perspective in mind, the amount of AR research with end user studies or evaluations of usability or user experience is generally very low. Swan and Gabbard (2005) explored over 260 AR publications, and noticed that only 38 (~14%) of those addressed some aspect of HCI and 21 (~8%) describe a formal user study. More recently, surveying AR-related papers between 1992 and 2007, Dünser et al. (2008) conclude that only roughly 10% of the papers have included some sort of user evaluation. As one probable result of this, the user interaction often does not take true advantage of the AR metaphors and its strengths, resulting in poorly designed interfaces.

The lack of user research has been characteristic to the AR field from the very start, which however, considering the premises and scientific backgrounds, is understandable. According to Anastassova et al. (2007), emerging technologies usually represent designers' pursuits of technical achievements and therefore the development is technology-driven, leaving user needs as a minor concern. It is true that the technology components and enablers still require a lot of development to meet even the minimum requirements for 3D and more interactive AR applications (for example, related to tracking and registration). Anastassova et al. (2007) also point out that the potential applications are often futuristic and the users lack skill to imagine the future possibilities and thus cannot express need for such. This is a half-truth that can be argued to be unravelable with appropriate research methods, and thus should not be used as an excuse to neglect user-centeredness in technology development.

Despite the quantitative lack of user research in AR, the following sections present some relevant publications relating to human factors, usability, and partly also on user experience of AR. Section 3.4.1 shortly reviews central publications on usability and human factors in AR. Section 3.4.2 presents a selection of papers with user evaluation results in the most related application areas. These give an overview of what kinds of user studies have been carried out and what kinds of usability and experiential issues have been highlighted especially in relation to mobile AR. Section 3.4.3 describes

papers that suggest methods, approaches, guidelines and considerations for user-centered design in the areas of AR and MR in general. Overall, as true mobile AR systems and research papers represent a minor part of the relevant literature, examples of both AR and MAR are discussed.

3.4.1 Studies on Human Factors and Usability of AR

The majority of user studies in AR and MAR have focused on usability and 'human factors', i.e., the technology-directed physiological, cognitive and behavioral user requirements. The research in these areas has been relatively active, especially with regard to perception issues, challenges with display and other output solutions, user task performance issues (e.g., Dünser et al. 2008), usability of interaction techniques (e.g., object selection and manipulation) (Choi & Kim 2012, Stanney 1995, Voida et al. 2005), and using AR in collaboration and communication (Billinghurst & Kato 2002).

Especially the perception issues in AR are numerous, as shown by the extensive review by Kruiff et al. (2010). For hand-held mobile devices, they emphasize for example the following factors to affect the perceived quality as well as the technological solutions: lens quality, color correctedness, environment illumination, occlusion and poor visibility of objects, rendering and resolution mismatch, reflections, display properties, and users' individual differences. Other related issues are, for example, calibration mismatches, lack of stereo vision, restricted FoV and viewpoint dependency, absence of shadows on virtual objects, accurate sense of depth and size, and limitations on image luminance, clarity and contrast (Drascic & Milgram 1996, Livingston 2005, Wither & Höllerer 2005). In addition, studies on display solutions and presentation cover, for example, experiments on text legibility with various drawing styles and contextual settings (Gabbard et al. 2006), depth judgment in optical see-through AR (Swan et al. 2006), and label placement in AR views (Azuma & Furmanski 2003).

Overall, studies such as above have been central proponents of the user-centered stance in AR. Paying attention to human factors is critical and needs to be taken into account well enough in MAR systems before being able to consider higher-level experiential design targets.

3.4.2 User studies Relating to UX of AR and MAR

The following presents a body of user studies that are the most relevant to the topics of the thesis. In most cases, the research target has been usability or user acceptance but some studies on experiential aspects exist as well. With regard to application areas, the focus is on casual mobile interactions, such as exploration of urban environments (the focusing is discussed more extensively in Section 4.1). In this regard, there are relevant papers with user studies about, for example, historical reconstruction and exploration, museums and exhibitions, map enhancement and navigation, and gaming.

To start with, exhibiting historical objects or areas has been a popular research area in MAR. Damala et al. (2008) present a fully functional prototype of an AR-enabled mobile multimedia museum guide that was evaluated with students, both with qualitative and quantitative means. The evaluation considered mostly usability of the UI and appropriateness of the content presentation. As main strengths of MAR they highlight the ease of spatial identification and localization of the

commented works of art in the gallery space, helping to better approach and appreciate the paintings, and the pupils having learned more by using the guide rather than if they had not used it.

A slightly more UX-oriented discussion on AR is presented by Barba et al. (2010), who present a handheld AR system called [inbox]. The system aims to demonstrate also the experiential aspects related to Physical-Virtual relationships (e.g., digital objects appearing inside/outside physical ones), the representational style (simple 2D images instead of 3D not to create a too authentic mixing of realities), embodied interaction (e.g., to create tension between the affordances of the physical and virtual objects), and increased awareness. They conclude that their holistic design approach requires delicate consideration of how to provide the users with opportunities for creative meaning making and how to, on the other hand, constrain their interactions to ensure a rich experience.

With regard to navigation, Morrison et al. (2009) present their findings from field trials of MapLens, which is an AR map using the magic lens metaphor to augmented paper maps. The participants of their study used MapLens to play a location-based game in a city centre. One of their main conclusions is that AR features facilitated place-making by allowing referencing to the physical world. The strongest potential of AR maps was seen to be their use as a collaborative tool. Regarding UX, rather small and inconsistent differences between the MapLens and a digital map were found.

Gaming has also been a fruitful context for MAR demonstrators. Avery et al. (2006) conducted a user study to measure how much users enjoyed playing an outdoor wearable/HMD-based AR game and how intuitive it was in contrast to a desktop PC version. With 44 participants, they found out that the AR game was rated significantly more enjoyable and more intuitive to use. Although it represented just one game in one environment, the AR experience was found to improve the gaming experience.

Cheok et al. (2002) present "Touch-Space", an embodied and social mixed reality game space that also regains the physical and social aspects of traditional game play: it allows tangible interactions between players as well as virtual objects. Their user study with 40 participants in collaborative settings showed collaborations between players in different levels of reality. With regard to experiential aspects, the participants generally felt much more entertained when compared to a desktop PC game, and most users reported a strong feeling of participation in the game. Similarly, in the "human pacman" study by Cheok et al. (2004) the participants were found to experience seamless links between the real and virtual worlds and a higher than ever level of sensory gratification.

A recent paper by Suhonen et al. (2012) takes a more UX-oriented approach and looks into users' expectations of MR in remote interpersonal communication and collaboration. Various user scenarios were first created together with the users and then evaluated in the second study. The results indicate that the expected advantages of MR in communication are its efficiency, richness of communication compared to traditional communication methods, and the increased feeling of social presence over distance. UX-related concerns include, e.g., the accuracy of interactions with virtual objects, the realism of avatars and virtual environment, the lack of physical presence, and loss of spontaneity.

Related to mixed reality in urban environments in general, Vaittinen et al. (2010) conducted a user study to gather potential users' needs for annotating locations in various day-to-day situations. They had nine participants keeping diaries for 12 days and report the situations in which a need for either

creating or acquiring an MR annotation about specific locations or objects. The created annotations varied in terms of categories of locations and targets, types of annotation (e.g., reviews, additional facts, invitations, questions), and how the annotation would be interacted with. As design implications, they state that such MR services for annotating locations should, for example, provide notifications about selected annotations nearby, support flexible selection of the target of annotation, and support collectively created annotations. In addition, Reid et al. (2005) carried out an extensive trial to study "magic moments", i.e., moments that are memorable and valued by a person, with a location-based system that augments urban contexts with virtual audio information when on site. Their interviews of 30 users indicate, e.g., experiences of immersion in the simulated situation, unexpected collisions of virtual and real (e.g., hearing a seagull cry in the headphones and then one flying past), confusion from not knowing what is real and what virtual, and seeing familiar surroundings with new eyes.

In regard to artistic applications, Jacucci et al. (2005) evaluated the tangible interaction of an AR painting and collage system that utilizes a physical brush to create digital textures on physical models. They report that users had difficulties in knowing to which part of the model some textures in a poster referred to, which led to problems in establishing a shared context or common ground. The brush as an interface tool was used in many ways: for example, for painting, erasing paint, zooming and rotating a texture, as well as for collaborative work and performing separate tasks on the same model. However, the resulting subjective experiences were not explicitly studied.

All in all, despite the multitude of publications on usability and human factors of AR, the field is lacking profound insight into the *experiential aspects* that MAR (and AR in general) could contribute to and what kind of experiential potential it has. To summarize the publications above, the mentioned aspects that can be regarded as experiential relate to the following:

- General enjoyment and entertainment
- Intuitiveness of use
- Richness of interaction
- Facilitating task accomplishment (e.g., identification, place-making)
- Perceptions on relationships between physical and virtual (e.g., confusion, seamlessness)
- Increased awareness and seeing surroundings with new eyes
- Feeling of participation and immersion

Most importantly, it seems that scientific publications about potential users' expectations of MAR services are virtually non-existent. This gap opens up a fruitful opportunity to build an explorative research agenda focusing particularly on user expectations and UX in the field of MAR.

3.4.3 Methodologies and Considerations for Design and Evaluation of AR

Dünser et al. (2008) argue that one reason for the lack of user research could be lack of knowledge on how to conduct the evaluations and what kind of methods and metrics to use. They report that in the few papers that have carried out user evaluation the methods have been mostly objective measurements, such as task completion times and error rates and various informal evaluations. Such

measures, however, reveal little about how the use of AR feels and what is its subjectively perceived value. Bowman et al. (2002) argue that performing user evaluations on non-traditional interactive systems requires new approaches and techniques, e.g., considering the challenges in making an intervention during use of a mixed reality environment. Bach and Scapin (2004) furthermore highlight a lack of common testing platforms and benchmarks in order to help compare and share the evaluation results. Similarly, the design of novel services requires guidelines – based on the evaluation results – that are specific to the type of interaction.

Various general methodologies and considerations based on UCD have been proposed by, e.g., Nilsson (2010) and Gabbard et al. (1999). Nilsson (2010) suggests to involve real end users in design and evaluation, and to make sure the tasks or scenarios are realistic, hence cementing the general principles of user-centered design. Gabbard et al. (1999) propose the process of user-centered design and evaluation of virtual environments to include, for example, user task analysis to create tentative guidelines and heuristics, expert guidelines-based evaluation to come up with representative user task scenarios and appropriate UI designs, formative user evaluation to iteratively refine UI designs, and summative comparative evaluation in the end. Furthermore, Gabbard and Swan (2008) suggest that user experiments should employ tasks that are representative in the application or domain, and that the equipment and environments in the studies should be such that are likely used in the actual use as well. Overall, despite the papers' original foci on ensuring usability, these methodologies and processes are more or less sound also for design and evaluation of UX. It is the used measures that distinguish usability design and evaluation from the same processes with regard to UX.

Gandy et al. (2010) present an interesting multi-method setup for inspecting how immersion factors affect the aspects of presence, performance, and physiological responses of a user. In gathering user data, they utilized physiological measurements, task performance measurements, interviews, and subjective questionnaires about the task load and the aspect of *AR presence*. The latter included items about, for example, naturalness of moving around in the environment, feeling like an observer vs. participant, awareness of event occurring in the surroundings, being able to move or manipulate objects in the environment, level of "drawn in", and feeling of comfort in interacting with the environment. Several items focused on the system's characteristics and related human factors: e.g., interfering user performance, display quality, modality consistency, and realism. Nevertheless, their questionnaire can be seen clearly as a step towards evaluating more experiential elements like *presence*. Takatalo et al. (2008) conclude presence in virtual environments in general to consist of dimensions of physical presence, situational involvement and competence (i.e., perceived skills, sense of control).

With regard to design, in 2001 Gabbard and Hix surveyed design guidelines in prior related research and built a consolidation of guidelines for AR systems in general. The guidelines mostly consider human factors and highlight, for example, supporting user's navigation (e.g., with landmarks and a compass), supporting multimodal and two-handed interaction, striving for high frame rates and low latency, allowing contextually adaptive virtual agents, allowing users to control the type and extent of information presented, and labeling the objects clearly to reflect their meaning and encourage user

engagement (Gabbard & Hix 2001). Despite some of them can be seen as 'obvious' in today's usability design practices, their summary is extensive and cites to a good number of prior research.

Dünser et al. (2007) combine general user-centered design principles with the particularities of AR systems and contexts of use. They emphasize eight aspects to be considered in design of AR:

(1) *affordances* provide a conceptual model that describe subject-object relationships and communicate the user what (and how) an AR system is used for
(2) *reducing cognitive overhead* refers to allowing the user to focus on her actual task instead of maneuvring the system
(3) *low physical effort* means that users should be able to accomplish a task with a minimum of interaction steps (e.g., reducing fatigue and simulator sickness)
(4) *ease of learning* to use the system in order to facilitate efficient use (e.g., self-descriptive labels, consistency and familiar user interface designs)
(5) *user satisfaction* refers to the subjective emotional satisfaction (as in UX theories) that are represented as, e.g., fun and 'wow' effects
(6) *flexibility in use* is, e.g., about utilizing different input and output modalities to support different users' preferences
(7) *responsiveness and feedback* means minimizing system lag in tracking and providing the user with information about the system status
(8) *error tolerance* means elimination of disturbances like jitter, 'jumping' and disappearing content

These are mostly about usability issues and considering different users. However, also user satisfaction as a general experiential element is brought up – perhaps for the first time in AR literature.

Finally, Träskbäck (2004) summarizes usability guidelines and user requirements for mixed reality applications. The guidelines from several sources (also from Gabbard & Hix 2001) suggest to, for example, exploit real world interaction in interacting with objects, present only information that is relevant to the user thus avoiding information fatigue, support users' orientation and sense of location in the mixed reality, and facilitate user-based content authoring in MR environment.

In conclusion, an important aspect to mention at this point is that although many of the following insights originate from general AR user research, the results and guidelines can be directly applied to mobile AR. After all, general AR design guidelines, usability design principles and evaluation methodologies can be considered as valid independent of the device platform or the context of use. Similarly, when regarding UX aspects, studies of other types of AR can inform MAR design and evaluation, and vice versa.

3.5 Summary

AR is a field of research that intertwines futuristic visions of ubiquitous computing, context-awareness and tangible interfaces through the augmentation of reality with virtual elements. Mobile AR based on smart phones holds the potential to make AR truly widespread in an extensive array of casual activities, for example by visualizing relevant location-based information content in the very context the user is. The interaction with MAR can be considered egocentric, contextually determined, tangible

and embodied, which makes it a powerful and intuitive tool to access and manipulate location- and object-based information.

As MAR is maturing as a technology, various services utilizing it can start evolving – such that truly take an advantage of the strengths of MAR and provide the user with long-term value. Nevertheless, MAR is still a "solution looking for problem" (Bowman et al. 2002); the most potential use cases and application areas are still being searched for. Perhaps this originates in the lack of user research in MAR: little is known about what potential users expect of the multifaceted nature of MAR, for example regarding user experience, possibilities in the interaction, potential contexts of use, and the ways of creating, sharing, browsing, and searching the AR content.

While the potential of MAR for innovative service design seems to be excellent, there are challenges when it comes to designing a rich and emotionally satisfactory user experience in MAR services. The challenges arise from not only the apparent design challenges of mobile devices and contexts (e.g., small screen size for content presentation and limited input) but also the novelties that MAR offers with regard to the interaction metaphor and mixing real with virtual. The area of MAR (and AR in general) seems to lack of appropriate user-centered design and evaluation methods and tools to consider especially the experiential aspects. The novelty of both MAR as a technology and UX as a theoretical framework, however, give much space to explore new concepts, to come up with novel services and to forge intriguing user experiences in this intersection.

4. Research Process

Chapter 1 presented the metatheoretical foundations, the overall approach, and the research questions of this research. This chapter summarizes the overall methodology and the research process from a practical point of view. First, based on the understanding of related research presented in Chapters 2 and 3, Section 4.1 describes further focusing decisions with regard to AR, UX and the application areas addressed in this thesis. Second, Section 4.2 describes the four studies comprising this thesis, as well as the participants and data gathering and analysis methods in them.

4.1 Conceptual and Methodological Focusing

First of all, to recapitulate Chapters 2 and 3, two central gaps in research knowledge can be identified.

(1) There is little empirical understanding of what expected user experience as a concept means and what the experiential expectations actually are – especially with regard to emerging technologies like MAR.
(2) Despite the apparent experiential potential in MAR, there is very little research focusing on the UX of this particular field.

Consequently, there is a need for methods and measures to scrutinize experiential aspects related to, for example, the augmented perception of one's environment, novel interacting metaphors, location- and object-awareness, embedded information accessed with AR, and generally any novelties that MAR offers. Undestanding of potential users' expectations helps identifying the experiential potential in this new field as well as creating specific design implications and evaluation measures to facilitate development of successful MAR services.

The aforementioned, however, offers a broad space to be researched, hence requiring the thesis to be further focused. The following further specifies the scope of the thesis with regard to the type and characteristics of AR (the technology), application areas and target user group, and what aspects of UX and expectations are specifically looked into (the user). The focus decisions are illustrated in Figure 10 and specified in the following.

With regard to AR, the focus is on *visual augmentation*, according to the original idea of AR. After all, vision has a central role in human's functional interaction and it can be easily utilized in UI design to attract attention. Vision is much about browsing the surroundings and perceiving the affordances in the environments, which are central aspects also in MAR. Furthermore, it was seen straightforward to use visual AR examples as stimuli and introductions for the participants in the studies.

Based on the justification in Chapters 1 and 3, the thesis focuses on *mobile AR*, that is, AR in mobile contexts and activities where a mobile device is used as the interface hardware. Stationary and laboratory-based AR systems and large spatial AR installations are purposely left aside. The studies covered both hand-held and head-mounted mobile interfaces but as the hardware was not in focus in gathering users' expectations, no differentiation between the types of devices is made in the results.

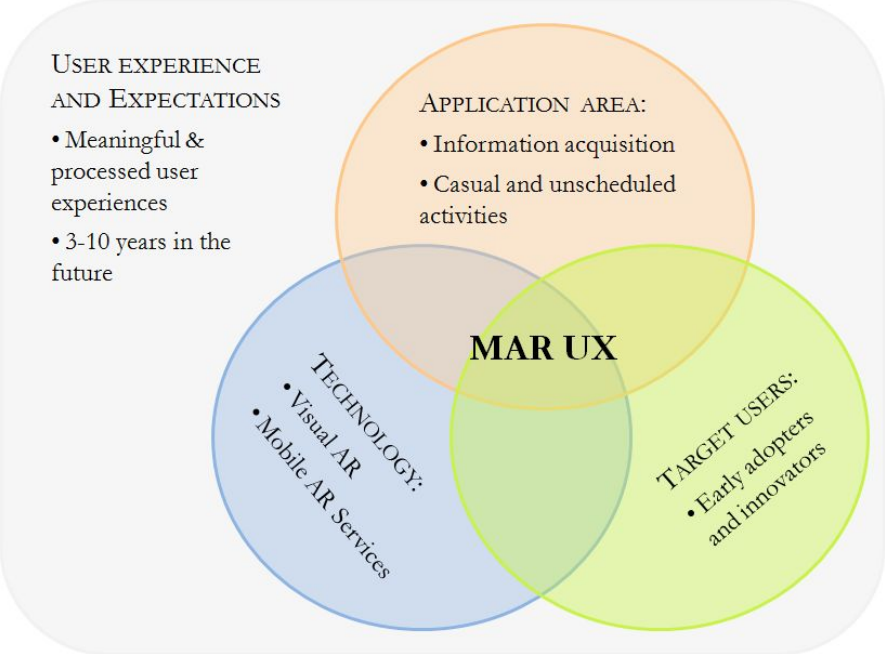

Figure 10. Focusing the scope of the thesis to specific types of AR, target users, application areas, and elements of user experience and expectations.

Furthermore, the expectations of MAR are viewed from the perspective of *MAR services*. A MAR service includes not only the technological system and devices and the application that offers certain functionalities, but also the AR information content and the way of interacting with MAR. This is seen as the entity that the users would perceive when interacting with MAR – as envisioned in the expectation studies. With this broad perspective, it is possible to look into not only the immediate expectations related to the devices and functionalities, but also the expectations related to the novel way of interacting with technology, the novel type of content, and the purpose and context of use.

As for actual experiences of MAR, the term *application* is used to refer to the first-generation MAR applications like Layar and Junaio. This is to distinguish between the (1) expectations and potential of future services and (2) the realities of the existing applications (i.e., not being very versatile demonstrators of the conceptual richness of MAR).

Regarding the possible application areas for MAR, a general focus is on *information acquisition in the context of casual and unscheduled activities*. A central part of people's activities in mobile contexts consist of running daily errands, searching for information about near-by things, wayfinding to places and objects, making purchase decisions and comparing products and services, exploration of the nearby environment, and spending time with various entertaining applications. Such casual but day-to-day aspects have not been addressed in prior MAR applications even though the area offers a diverse design space for activities that take place relatively frequently. Although this focus is still rather broad, it leaves out areas like professional and industrial applications (e.g., medical, construction, military), education and learning, collaborative activities, and AR in vehicles.

Concerning the various user research stances, the focus is on *user experience*. Following a central principle in grounded theory, no specific UX frameworks are used for classification purposes in the analysis of qualitative data (Strauss & Corbin 1990). For analysis purposes, UX is regarded as

subjective, temporally changing and depending on the user, system and context. Nevertheless, existing UX frameworks are used for contrasting and reflecting the results in Section 6.2. Furthermore, *user acceptance* (see, e.g., Venkatesh 2003) is a secondary framework as it can be seen to relate to user expectations as well. User acceptance as an older concept than UX has brought about various validated metrics that were used to support gathering theoretically as extensive data as possible in the studies. This perspective was used especially to look into what aspects of MAR affect especially the *perceived usefulness* and overall *willingness to use*. Aspects *not* considered in this regard are the process of taking the consumer-targeted applications into use or the elements that have contributed to the users' selection processes. The empirical findings related to subjective statements and questions on user acceptance are reported in the papers but, for the sake of focusing, not summarized in the thesis.

With regard to the types of experience, the focus is on the user's personal and first-hand experiences that are *meaningful*, *processed* and *conscious* – instead of merely sensory or emotional experiences, or experiences of which the user is not aware. In the reflection framework by Wright et al. (2008) this relates to the processes of *interpreting* and *reflecting*, and partly also to *recounting* and *appropriating*. After all, meaningful and memorable experiences are important in judging the overall value of a product or service and they play a role in sharing experiences with other people. Furthermore, it would be inaccurate to investingate purely emotional or sensory experiences with merely qualitative interviewing. This leaves out, e.g., routine experiences that the user is accustomed to and implicit socially observed experiences where the user is not directly interacting with the system.

As for expectations, the focus is on the *types and targets of the expectations* – not the process of how expectations form based on earlier experiences, or the relative strengths of the different expectations. As introduced in Section 2.4, expectations are here understood very broadly. Most often, the expectations were manifested as participants' *needs* for information or suggestions of how to use MAR in various situations, that is, positive expectations that can be seen as "ideal expectations or desires" (cf. Teas 1993). Such needs might stem from, for example, the participants' personalities and personal values. In addition, some expectations were manifested as *requirements* or *presumptions* stemming from their knowledge of prior technologies that allow similar functionalities (i.e., "normative 'should' expectations" and "experience-based norms" according to Teas 1993). In planning studies of such a new ground, it was seen best to not only focus too strictly on, e.g., presumptions or needs but, rather, to understand very broadly how people perceive and anticipate a novel technology. In the meta-analysis of the studies (see Section 4.2.5), however, especially the needs and desires were focused on due to their probable value as desirable experiential targets in design and evaluation.

Furthermore, the time scale was set to *3-10 years in the future* in order to help the participants of the studies not to be limited to concurrent technological or societal limitations. At the time of conducting the expectations studies, MAR was not a publicly well-known concept. The prior familiarity with MAR was not inquired consistently from every participant but all those who were inquired orally in Studies 1 and 2 replied that they were new to the topic. In the online survey (Study 3) this aspect was not inquired but, based on the answers and backgrounds of the participants, we can interpret that most had no prior knowledge of MAR in this study either. Consequently, all the studies included

textual and visual of introductions (i.e., stimulus material) to help the participants orient to the futuristic topic of MAR. The stimuli included, e.g., rough concept images of augmented content on various real objects and places, textual scenarios describing future MAR services and their use, and the surrounding environment as a contextual stimulus in Study 2 (see Section 4.2 for more detailed descriptions). The used stimuli naturally might have affected the participants' expectations (i.e., priming effect), which is discussed more thoroughly in Section 7.1.

Finally, the target user group in the expectations studies was broadly set to *early adopters* and *innovators* (Rogers 1995), i.e., people who are oriented in using modern information technology and thus prone to appropriate new technologies in the near future. In practice, this meant recruiting people from forums where such people could be reached (e.g., AR-related blogs and discussion forums, universities' mailing lists, social media; see the papers and Section 4.2 for details). The belongingness to this group of people was measured in each study in terms of level of technological orientation and attitudes towards technology. Considering the diffusion of technology, we anticipated it to be revealing to understand how early adopters value the technology, to what purposes they see it useful for, and what are the issues that they see to stand in the way of making the technology more widespread – before studying the majority of consumers. Research on early adopters can allow identifying the most fundamental issues with the current and potential solutions and envisioning more appropriate application areas for the future. For example, Von Hippel (2005) suggests that, for the purposes of democratization of innovation, companies should follow their "lead users" and their development of existing products for their own use in order to find profitable new products. Furthermore, a practical reason is that early adopters, being interested in technology, are easier to be involved in especially lengthy interviews than the majorities. This target group does not allow generalization of the results to entire populations: they probably have higher and more positively biased expectations and perceptions of emerging technologies than the majority. Generalization, however, was not either the goal with the qualitative research approach. Moreover, the assumedly more moderate expectations of the majorities would hardly serve as inspiring design targets for future MAR services.

4.2 Research Process and the Studies

The overall outline of the research process consists of four studies and five main phases, as illustrated in Figure 11. Altogether 401 persons with varying nationalities and backgrounds participated in the four studies, as either interview participants (51) or survey respondents (350).

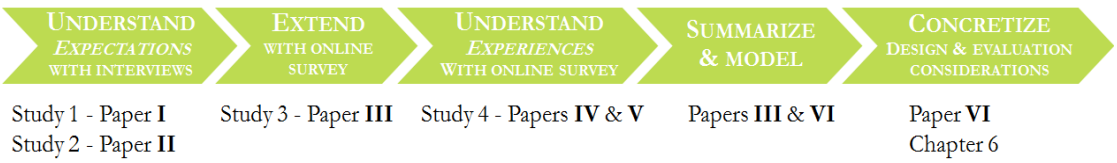

Figure 11. The overall research process in terms of the main goals of the phases, and which studies contributed to each of the publications.

In the beginning of the research process, the area of MAR in terms of user expectations and experiences was evidently obscure and the overall approach had to be very explorative and open-minded by nature. The first data that was gathered in Study 1 explored the area and the main phenomena and aspects related to it with relatively open approach. This allowed designing a more in-depth study (Study 2) that had more specified interview questions and was conducted in a context that could be potential for MAR services in the future. Furthermore, the detailed understanding about the expectations from Study 2 allowed designing Study 3 to extensively investigate the area with a quantitative approach and assess the differences between different types of user scenarios. After the expectation studies, the next phase focused on assessing and gathering examples of actual experiences of the first-generation MAR applications (Study 4).

The following sections summarize each study with regard to the overall research setting, the methodology, and the participants. In addition, Section 4.2.5 describes the meta-analysis of the studies in terms of identifying experiential expectations in the data and consolidating it.

4.2.1 Study 1: Focus Groups to Study Expectations of MAR

To take the first steps towards understanding potential users' expectations of MAR, five in-lab focus group sessions were carried out with people from different target groups. The goal was to explore the expectations and early impressions of MAR and needs for digital information based on illustrated multi-part scenarios in two focus areas: (1) tourism (in an unfamiliar environment) and (2) casual activities (in a familiar environment). Examples of the used stimuli can be found in Paper **I**. The term MMR (Mobile Mixed Reality) was still used at this point to refer to the broader concept. However, the examples given and the discussion in fact focused on mobile AR and, e.g., augmented virtuality was not discussed. The study was carried out in December 2008.

- **Participants**: 23 Finnish (13 male and 10 female), ages varying from 18 to 59 (Mdn 26). Most could be seen as early adopters but also less technologically oriented were involved in certain groups. One session per user group: active travelers (6), senior high school students (4), tech-savvy people (4), wellness-oriented people (5), people with eco-friendly values (4). Recruiting channels included university mailing lists, list of people interested in user testing, and direct contacts to high schools
- **Procedure and data gathering**: The primary data was elicited in semi-structured group interviewing that lasted 1-1.5 hours (hand-written notes and audio recordings, i.e., qualitative data). The interview themes covered, for example, needs for information with MMR in various situations, interaction with the MMR information, and feelings evoked from the scenarios. A short background questionnaire produced quantitative data about the participants' backgrounds and another in the end about the overall expected experience
- **Data analysis**: transcribing the interview notes, identification of themes in group of four researchers, and finally categorizing the data and refining the themes. Simple statistics of the questionnaire data
- Contributed to **RQ I** and Papers **I** and **VI**

4.2.2 Study 2: Contextual Interviews in Shopping Centers to Study Expectations of MAR

The second study incorporated a context-based research setting to create a more authentic and stimulating environment in which to gather user data. In addition to gathering expectations about the overall UX, also use cases and needs for MAR services in the particular context were invented. To introduce to the concept of MAR, simple illustrations of augmented content on a street view were used, hence mainly emphasizing the content being location-based and overlaid on the real-world view. Altogether 16 interviews were held in two different shopping centres in Tampere, Finland, and the users participated as individuals, pairs or groups. The study was carried out in February-March 2009.

- **Participants**: 28 Finnish (12 male and 16 female), ages varying from 20 to 42 (Mdn 24). Mostly early adopters. The majority was familiar with the locations in question. In the recruitment (with help of various mailing lists and billboard ads), the participants were required to be at least somewhat interested in new technical products. The background questionnaires implied the majority to be early adopters
- **Procedure and data gathering**: The primary data was elicited in 50-70-minute semi-structured interviews about participants' expectations and needs for MAR and the in situ inventing of how to use MAR services in the current context and based on one's normal activities there. Short background and ending questionnaires were used similarly as in Study 1.
- **Data analysis**: Thematic multi-phase and multi-level categorization with the help of a physical affinity diagram (Beyer & Holtzblatt 1998) in a group of 4-5 researchers. After this, a meta-analysis to identify the experiential expectations was carried out
- Contributed to **RQ I-i** and **RQ I-ii**, and Papers **II** and **VI**

4.2.3 Study 3: Online Survey to Evaluate Expectations of MAR Services Based on Five Futuristic Scenarios

The third study continued the research agenda with a more structured and quantitative approach. An online survey was conducted to evaluate the user acceptance and expected UX of five different mobile AR scenarios. In addition, the participants evaluated MAR services in general, especially with regard to the potential, benefits and risks of MAR in the near future. The scenarios – partially based on the expectations identified in Studies 1 and 2 – presented the contexts and activities of (1) a bus trip, (2) jogging with data glasses, (3) shopping furniture, (4) a virtual mirror for trying out clothes and accessories, and (5) street art in the form of AR graffiti (see Paper **III** for detailed descriptions). Overall, the scenarios were rather positively presented, mainly demonstrating the possibilities of future MAR services and not particularly underlining potential risks or problems in using them. Before the scenarios, a short concept description with illustrations was given to educate the participants about the overall concept of AR (similar as in Studies 1 and 2). Both Finnish and English versions of the survey were launched. The study was carried out in April 2009.

- **Participants**: 180 Finnish and 80 with various nationalities (127 male and 133 female), ages varying from 17 to 64 (Mnd 28). Regaring technological orientation, most were highly (120) or moderately (105) oriented (can be seen as early adopters or innovators) but also 31 less technologically oriented took part. Participants were recruited via mailing lists targeted to people interested in user testing, and from students and staff of a technical university. No pre-selection of the respondents was carried out
- **Procedure and data gathering**: The survey consisted of open questions and various subjective statements about UX and acceptance with a Likert-scale. The survey took approx. 15-20 minutes to complete. As stimulus, the scenarios were described as text (approx. 250-300 words) and illustrated with a depictive image
- **Data analysis**: Qualitative analysis of the data from open questions (i.e., thematic categorization and quantification by two researchers), statistics of statement questions, Friedman's tests and Mann-Whitney's U-tests to assess statistical effects of background variables
- Contributed to **RQ I** and Papers **III** and **VI**

4.2.4 Study 4: Online Survey to Evaluate UX of Current MAR Applications

The fourth study changed the focus on the actual UX of publicly available MAR applications that existed at the time of the study, April 2011. An online survey study was conducted, aiming to examine the overall use, user experience, and user acceptance of first-generation applications like Layar, Junaio, Wikitude and Google Goggles. The survey consisted of several sections about participants' overall practices of using MAR applications, descriptions of their most satisfying and unsatisfying highlight experiences with MAR, and various questions about UX and acceptance overall. This allowed evaluating the applications' experiential qualities as well as the most meaningful user experiences.

- **Participants**: 90 persons (74 male and 15 female) representing 18 different nationalities (30% Finnish), ages varying from 16 to 65 (Mdn 28). The technological orientation was measured to be high, implying that the participants could be regarded as early adopters. The amount of experience with MAR applications varied extensively (see Paper **IV**). Participants were recruited through various AR-related blogs, social media and mailing lists
- **Procedure and data gathering**: Both open questions and subjective statements with Likert and frequency scales were utilized. Regarding acceptance (intention to use), the statements by Hsu et al. (2007) were applied. For UX, mostly self-developed subjective statements were used. The critical incident technique (CIT; Gremler 2004) was utilized to gather the descriptions of the highlight experiences
- **Data analysis**: Qualitative analysis of the data from open questions (thematic categorization and quantification by two researchers, interrater reliability measured), statistics of the subjective statements, Mann-Whitney's U-tests to evaluate various differences statistically
- Contributed to **RQ II** and Papers **IV** and **V**

4.2.5 Meta-Analysis of the Experiential Aspects in the Expectations

As discussed in Section 4.1, the studies dealt with expectations on different levels and from different perspectives. The gathered user data was not only about participants' expectations of *experiential aspects* but also about *user needs*, *desires* and *requirements* related to various elements in the MAR service entity. In fact, inquiring the participants' expectations about the experience itself (**RQ I-i**) was anticipated to be challenging in planning the research, and it had to be approached with various interview questions and survey statements from different points of views. The questions were about, for example, how the context or one's activity would affect how the MAR service is used, the strengths, possibilities and weaknesses of MAR, and the overall value that MAR would provide. Consequently, the consolidation of the expected experiences in the different studies is based on a qualitative cross analysis.

With the help of a data walkthrough and thematic analysis, the data in each study was systematically re-examined to identify characteristics of experience behind the mentioned user needs, requirements, perceived value etc. – either from users' explicit mentions or implicit allusions. For example, the aspects presented as design requirements in Paper **II** have been transmuted into desirable experiences by identifying the desires behind the requirements.

Furthermore, a meta-analysis across the expectations studies (Studies 1, 2 and 3) was conducted while preparing Paper **VI** and this introductory part of the thesis. The analysis was carried out solely by the author and was targeted to summarize entire breadth of the categories of experience and service components identified in the expectations. The analysis was based on scrutinizing the earlier experience descriptions, the results of earlier analysis, such as the affinity diagram, and partially also the raw data from the studies (i.e., transcripts and recordings). This process aimed to identify additional themes in the data – e.g., such that earlier were hidden among abstract descriptions – and to further conceptually clarify the experience categories. In addition, based on thematic analysis, the experience categories were further grouped into the six general classes described in Section 5.1.1. Finally, as the analysis was carried out as solo and for purposes of qualitative clarification and summarization, interrater reliability or similar measures neither were calculated, nor was it seen necessary to do so.

5. Results

The empirical results are presented according to the research questions. Section 5.1 first summarizes the characteristics of expected experience of MAR services (**RQ I-i**) and how they relate to different service components (**RQ I-ii**). Similarly, Section 5.2 summarizes the actual experiences of current MAR applications (**RQ II-i**) and their overall experiential qualities (RQ **II-ii**). Section 5.3 summarizes the aspects related to UX in the field of MAR by describing a visualized *MAR UX* framework.

5.1 Expected User Experience of MAR Services

The first part of the thesis research addressed user experience through the perspective of expectations. This comprises of (1) different characteristics of UX that were expected of using future MAR services and (2) service components that contribute to and influence the experiences. After this conceptual clarification, Section 5.1.3 summarizes the aforementioned, and reflects upon their relations.

5.1.1 Characteristics of Expected User Experience

The categories described in this section represent specific characteristics of expected user experience that were identified in Studies 1, 2 and 3. The target was not to form an absolute categorization, based on which to unambiguously classify and quantify experiences of MAR. Instead, the categories are meant to offer concepts with the help of which to identify various experiences and introduce the most central experiential aspects in this specific field. Therefore, the categories can be partially overlapping and represent slightly different levels of abstraction.

The descriptions of the expected experiences are based on those in Paper **VI**, however slightly condensed and refined. The identified categories of experience are further grouped into six classes that represent abstract-level types of UX in which the experiences *mainly* belong to: (1) instrumental experiences, (2) cognitive and epistemic experiences, (3) emotional experiences, (4) sensory experiences, (5) motivational experiences, and (6) social experiences. The classes are based on the typology by Buccini and Padovani (2007) but have been slightly processed to fit the scope of this thesis. Similarly as with the UX characteristics categories, the grouping is not intended to be all-inclusive and exclusionary but to provide the reader with further structure and aspects to consider in internalizing the various experiences. Later, Section 5.1.3 summarizes in which studies each of the categories were present and on which service components they are based.

Instrumental Experiences

Instrumental experiences demonstrate accomplishment, feeling of being supported or fortified by technology, appropriateness in using technology, and other pragmatic and utilitarian perceptions of service use. The experiences are based on the instrumental value of technology serving as a tool for the user's activities.

- *Empowerment* is about the feelings of powerfulness and achievement – being provided with novel possibilities and instruments for accessing, creating, and utilizing digital information in mobile contexts. The expansion of human perception and activities was expected to help gaining new insights and performing technology-mediated activities that have been unavailable before (a common expectation through studies 1-3). MAR allows perceiving new aspects of the physical environment through a ubiquitous access to location- and object-related information with a visually comprehensive and pervasive interface.
- *Efficiency* describes the user's feeling of being able to perform everyday activities and accomplish practical goals with less effort and time. Especially in Study 2, MAR services were expected to provide a very powerful and easy-to-understand interface to access location- and object-related digital information 'in situ' in mobile contexts. For example, when compared to use of the Internet or map-based LBS, less effort is needed in specifying the nearby point of interest about which one is trying to acquire information.
- *Meaningfulness* relates to the MAR service appearing personally meaningful and relevant in the user's current context and activity. MAR was expected to show only the content that corresponds to the surrounding visible things in the real world, thus making it feel relevant and worthwhile in the current location. Expectations of content being personalized based on the user's current needs and behavior were emphasized especially in Study 1.

Cognitive and Epistemic Experiences

The *cognitive and epistemic* experiences relate to thoughts, conceptualization and rationality. Such experiences stem from, e.g., the service's semantic qualities (e.g., what metaphors and conceptual models it is based on) and its capabilities of arousing curiosity and satisfying a desire for knowledge.

- *Awareness* describes the sense of becoming aware of, realizing something about or gaining a new insight into one's surroundings. With MAR, the embedded, latent, digital information related to locations and objects becomes perceivable and explicit. Hence, awareness can be manifested as (1) the momentary awareness and discovery of the current surroundings in situ (esp. unfamiliar environments), (2) the increased overall understanding of a place or object over time (esp. familiar locations), and as a special requirement for (3) awareness of the reality's physical risks that might remain unnoticed because of being too immersed in the AR.
- *Intuitiveness* relates to the feeling of naturalness and human-likeness of interacting with the AR content. First, intuitiveness is based on the ontology of information being related to physical locations or objects and the MAR content being superimposed only on observable things. Second, MAR allows rich and multimodal interaction that mimics the already familiar interactions in the real world and with other people: the interaction affordances are related to the things in reality, the interaction is instant and continuous, it is ego-centered, and it can allow direct manipulation of the field of view and the virtual objects.
- *Control* in this context is about the sense of controlling the mixing of the realities and the extent to which the service is proactive and knows about the user (i.e., a more comprehensive

sense of control in contrast to the usability-related control of the state of a UI). The extent of virtual content was expected to be modifiable by the user, depending on the situation – from intensive mixing with the virtual to no AR and full focus on the real world (e.g., jogging scenario in Study 3). Similarly, control over how much is known about the user would lower the anxiety of being tracked or supervised or the fear of losing sovereignty.

- *Trust* refers to the experience of being able to rely on the acquired AR content. It is based on the perceived reliability and validity of the information, and is important especially in information-dependent activities like navigation in unfamiliar places or decision-making between products (as in Study 2). In addition to the faultlessness and timeliness of the content, a critical requirement for this experience was mentioned to be the realism and correspondence of digital MAR models when aiming to replace a traditionally physical activity with a virtual (e.g., trying out clothes with a 'virtual mirror' in Study 3).

Emotional Experiences

Emotional experiences relate to the subjective, primarily emotional responses originated from the use of a service: for example pleasure, evoking memories and catalyzing positively valued feelings overall. The other meaningful experiences are often accompanied with emotional experiences like these.

- *Amazement* relates to the feeling of having experienced something extraordinary or novel. In MAR, amazement was expected to be emphasized especially in the first time of use, thus attributed especially to the charm of novelty. However, it can also be considered as the emotional element in the experiences of *awareness*, *empowerment*, and *inspiration*, which opens up possibilities in creating positive amazement also after the charm of novelty.
- *Surprise* is about positive astonishment, 'wow-effect' and surpassing expectations in general. Surprise has also *cognitive* elements (e.g., proactively pleasing the desire for knowledge) but it is here understood as the emotionally pleasing aspect. It was expected to originate from, e.g., proactively receiving contextually relevant and extraordinary information with the help of the pervasive AR visualization, and the service performing better than expected.
- *Playfulness* refers to feelings of amusement, frolicsomeness and joy in general. Playful MAR was expected to be present both with services that explicitly aim to entertain and with pragmatic services where the pervasiveness of AR, the novel way of interacting, and the accessed content can evoke playful feelings (highlighted especially in Study 2). Gaming-like and playful aspects in MAR content or interaction can further catalyze experiences like inspiration, surprise and amazement.
- *Liveliness* relates to the feeling of continuous change and accumulation of the service and the physical environment. A MAR service environment with varying and constantly changing content was expected to feel vivid and dynamic, thus evoke positive feelings of vivacity, revive pleasing memories and facilitate interaction between service users. This would derive not only from socially constructed (user-created) MAR content, but also from the pervasiveness of AR as an interface.

Sensory Experiences

Here, *sensory experiences* relate to such sensory-perceptual experiences that are not purely visceral but are also conceptually processed and the user is aware of them. These originate from the service's capability to arouse aesthetic, captivating and multimodal AR stimuli – thus affecting on the user's perception of the surroundings world and its interactivity.

- *Captivation* describes the feeling of being immersed and engaged in the interaction with the mixed reality environment. MAR as an interface was expected to captivate the attention of the user, engage or orient the user towards further interaction with the various elements of the realities (esp. highlighted in Study 2), and even lead to a feelings of *presence* ("being there") in the environment and *flow* in one's activities. On the other hand, AR should not disturb the understanding of what is real/virtual or the enjoying of the real world.
- *Tangibility* describes the sense of physicality and tangibility in interacting with the augmented environment. The content and the services accessed via MAR were expected to seem a concrete and integral part of the environment. In addition, the *transparency* of devices in MAR interaction allows the user to concentrate on the MAR environment instead of the interaction per se. Tangibility, along with captivation, can lead to feelings of presence and unity with the surroundings.

Social Experiences

Social experiences relate to human-to-human interactions that are intermediated by technology. These originate from service features that allow building or communicating one's identity or status, provide a channel for self-expression, or otherwise support social user values, such as feeling of relatedness.

- *Connectedness* relates to the feelings of relatedness and overall pleasure from social interaction. MAR services were expected to offer novel ways for reality-based mediated social interaction and communication. The social interaction aspect was brought up mostly as indirect interaction through product-related comments and other content shared by any other service users. Additionally, locating familiar people and being aware of friends nearby with the help of MAR could facilitate face-to-face interaction.
- *Collectivity* relates closely to connectedness but focuses on the feeling of belonging and participating into a user community and the service content being collectively constructed by users rather than by commercial actors. Collectively producing and contributing to the MAR service content can result in a *sense of community* and thus facilitate further interaction and constant accumulation of service content. In addition to explicit content sharing, it can be simply statistics about users' activities with the service (e.g., choice of products).
- *Privacy* relates to the (1) sense of privacy resulting from what information about the user is logged by the service and publicly available, and (2) the sense of social awkwardness that results from the obtrusive way of interacting with MAR. Especially user's location and activity status were emphasized as something of which the user should retain the control.

Motivational and Behavioral Experiences

Finally, *motivational and behavioral* experiences are created when the use or owning a service causes a certain behavior in the users: e.g., inspiring, motivating or persuading them to do something or pursue a goal with the help of technology – i.e., change behavior from earlier.

- *Inspiration* relates to feelings of being stimulated, curious about the new reality, and eager to try new things or appropriate the MAR service for new purposes. AR interaction was expected to have the power to inspire and stimulate – considering, e.g., mixing realities and types of information, exposing the immaterial values related to objects and locations, extent of fields where AR could be utilized, and the content being user-created. The physical surroundings could be used as a visual platform for MAR games, art, or entertainment, thus creating new possibilities for assigning new purposes to the service platform.
- *Motivation* is about the feeling of being encouraged and motivated to participate in the service community and contribute to its content, or to do tedious personal tasks with the help of a MAR service. This was expected based on the novelty values of MAR, especially the interaction metaphor and personalization. Furthermore, the immediacy and pervasiveness of AR interaction allows content created by a user to be easily enjoyed or utilized by others.
- *Creativity* represents self-expressive and artistic feelings in users creating AR content and mixing the digital with the reality in previously unimaginable ways. AR was seen to have potential to trigger imagination and serve as a fruitful interface to demonstrate artistic creativity, for example by utilizing the reality as a physical context and frame for digital decorations, artwork and refashioning based on video, audio, or imagery.

All in all, the described experiences can be considered as positive and satisfying experiences – something for the user to pursue and the designer to target making possible. This stems from the fact that participants mostly expressed expectations that they look forward to and consider desirable. However, this is also deliberate in order to provide a consistent categorization in this regard. Naturally, negative experiences and risks (i.e., avoidable design issues) were also expected to some extent but they have been merged with the descriptions of the positively colored categories above. For example, some of the desirable experiences are partially defined through the lack of related negatively perceived aspects.

In retrospect to the categories presented in Paper **VI**, there are some differences. Paper **VI** focuses more strictly on experiences that could be seen to be consequences of the element of AR. Hence, the categories above complements them with a few new ones in order to match with the broader scope of the thesis – including also such experiences that are not that dependent on the element of AR and thus not that useful as design targets for MAR in particular. The new categories are *control* and *trust*. The category of *meaningfulness* in Paper **VI** was divided into *meaningfulness* and *trust*, and the category of *collectivity & connectedness* was divided as well. This was done in order to allow more attention to the various aspects that these broader categories covered. Furthermore, a few terms have been changed to such that are more descriptive and focus on the *user experience* rather than the *qualities of the service*.

5.1.2 Service Components Contributing to the Experiences

In addition to identifying various possible experiences, it is important to understand what kind of elements and features (termed as service *components* in the following) MAR services are expected to involve, and to which of these components are the expected experiences attributed. Depending on the success of their design, various service components can enable or disable an experience to arise, evoke or initiate it, and catalyse or stimulate it or its valence and strength. The following categories describe such service components to that the participants explicitly expected to be salient in MAR services.

The descriptions follow the categorization of Hassenzahl (2004) that highlights four elements from which the experiences can originate in technology use: (1) *information content* that is accessed, created and manipulated, as well as its characteristics, such as origin and perceived quality and relevance; (2) *functionalities* that the service provides; (3) *presentation* and interface to the content and technology; and (4) *interaction* through which the service is controlled and reacted to. The analysis of the components has developed over time and from publication to another (e.g., Papers **II** & **VI**): it has become more fine-grained and precise in terms of identifying various service components that play a role in formation of the experiences. The identified service components are as follows:

- **Presentation – *Augmentation*** refers to the characteristics of augmented reality as the system output and way of visualizing the reality-related digital content. The expectations related largely to the amount of presenting AR content. For example, Paper **I** emphasizes that the amount of information and the interaction modality should be controllable by the users and in accordance with their preferences. The affordances (or *cues*) of digital interactivity and available information in the environment were expected to be subtle and contextually defined. In some cases, visual cues were expected to be supplemented with audible or haptic cues – especially with regard to the most important information or when the user is not actively browsing the AR view. The requirements of authenticity and high level of realism of the content presentation were brought up as well. However, with such an intangible research set up, no specific expectations were stated considering, e.g., the placement on the screen, lighting conditions, or how to handle occlusions.
- **Interaction – *Input and control*** refers to the way of providing input to the mobile devices, and hence controlling and interacting with the augmented environment and its content. The latter means not only browsing the AR environment to access information but also creating, managing and enriching the AR content in the service. The expectations of future ways of interacting with the system were high here as well. As the user's attention is largely reserved to coping in the physical environment, high amounts of attention or physical resources like the user's hands were expected not to be reserved continuously (e.g., to hold a mobile device upwards in order to browse the content through the camera view). The participants of Study 2 expected it to be challenging the service to determine with which digital content object the user wishes to interact. High-accuracy pointing methods like finger- or glove-based interaction were thus expected.

- **Content – *Information embedding*** means that real-world objects and locations are embedded with or linked to related digital content that is accessed with the help of the AR interface (i.e., "physical browsing"). MAR content was envisioned in many forms, related to, for example, places, products, public spaces, public transportation, and services in the real world. Such 'intelligent' objects were expected to be networked together and make themselves recognizable through MAR. Many of the expectations related to content are directed towards this component: e.g., relevance, tangibility, and the need to tag and bookmark the browsed information to ease findability later on. Another significant expectation in Paper **II** was about locating and navigating to important services like banking services, toilets, elevators and exits, as well as places outside the current physical context.
- **Content – *Community-created content*** refers to the MAR content being user-created, crowd-sourced or otherwise socially constructed, as well as the content being modifiable and increasable by the service users. Most content in consumer-targeted casual MAR services was expected to be user-created for the particular service, aggregated from existing LBS, and in few cases also created by service providers and other commercial parties. Especially in Paper **II**, active updating, high number of contributors and familiar people as information sources were seen to raise the trustworthiness and the relevance of the information. User-generated content as a recently well-established phenomenon in the Internet and map-based services probably explains such expectations also concerning MAR services.
- **Functionality – *Contextuality and personalization*** is about service functionalities and content being personalized to the user as well as determined by the user's current context. Personalization adds relevance to the reality-embedded content, thus facilitating the activities carried out in the physical world (e.g., purchase decisions). MAR services were also expected to learn the user's interest and needs over time to allow more and more personalization. Furthermore, some services were expected to be available only in particular locations or alongside specific objects (e.g., initiating buying a movie ticket through a poster with MAR).
- **Functionality – *Proactivity*** relates to the autonomity of the service and the service-originated initiation of the user-service interaction. This is closely related to contextuality as a MAR service was seen to be aware of the user's momentary needs to be able to adapt and proactively provide the user with something extraordinary and personally relevant in the current context – thus creating an experience of surprise. For example, MAR services were visioned to suggest personally interesting products nearby, prefilter the available information, and serve as location-specific reminders. In study 3, the respondents were interested in acquiring information automatically especially in unfamiliar environments, about product recommendations and special prizes of browsed products, as reminders what to buy, and related to unexpected issues in the surroundings.
- **Functionality and Interaction – *Mobility*** refers to the technology being usable in mobile contexts and activities in general, and allowing interaction "anytime, anywhere". In addition, it refers to having mobile devices, such as smart phones or tablet computers, as interaction

devices and utilizing the interaction techniques they currently provide (e.g., touch UIs and speech input). The current processing power and capabilities to render 3D objects and animations probably has affected the participants' expectations to some extent.

Overall, the diversity of the components implies that the potential users' expectations were often directed to other elements than AR per se, and that the concept of a MAR service was understood very comprehensively. This also means that the value of AR as a way of visualizing and interacting with information was not assessed as much as expected in the beginning of the research process. Especially the most negatively regarded comments related to other functionalities or the information content – not to how the information in the example was accessed and interacted with. This implies that the potential users did not judge or address expectations to the services based on which technologies the services utilize but based on their instrumental and experiential value to the user.

5.1.3 On the Relation of Expected Experiences and Service Components

The overall expected UX of MAR services can be seen to (1) consist of the various experience characteristics and (2) be based on the aforementioned components of the technological fabric of MAR. The service components can be said to play a role in initiating, creating, or catalyzing the experience categories, thus affecting how the UX of MAR is formed. Each experience category can result from one or several of the components, naturally depending also on the context and the user. Table 3 summarizes the expectations in terms of (1) in which studies each category was identified and (2) to which of the service components the expected experiences could be seen to mostly attribute.

Table 3. Summary of which studies the expected characteristics of experience arose from and insights into which service components (in alphabetical order) the experiences relate to.

Experience class	Category of UX characteristic	Identified in studies	Service components contributing to the UX characteristic (based on author's insights)
Instrumental	*Empowerment*	1, 2, 3	Augmentation, Embedding, Proactivity
	Efficiency	2, 3	Augmentation, Contextuality, Embedding
	Meaningfulness	1, 3	Contextuality, Community-created, Embedding
Cognitive and epistemic	*Awareness*	2, 3	Augment., Embed., Proactivity, Comm-created
	Intuitiveness	1, 2	Augmentation, Input, Embedding
	Control	2	Augmentation, Input, Mobility
	Trust	1, 2, 3	Community-created, Mobility
Emotional	*Amazement*	3	Augmentation, Input, Proactivity
	Surprise	2	Community-created, Contextuality, Proactivity
	Playfulness	2, 3	Augment., Comm.-Created, Embed., Input
	Liveliness	2	Augmentation, Community-Created, Embed.
Sensory	*Captivation*	2	Augmentation, Input
	Tangibility	1, 2	Augmentation, Embedding, Input
Social	*Connectedness*	1, 2, 3	Embedding, Mobility
	Collectivity	1, 2	Embedding, Community-Created
	Privacy	1, 2	Contextuality, Input
Motivational and behavioral	*Inspiration*	2, 3	Augment., Comm.-created, Context., Embed.
	Motivation	3	Augmentation, Comm.-created, Contextuality
	Creativity	1, 2, 3	Augmentation, Embedding

The numbers of in how many studies each experience was present are merely suggestive, and should not be looked too closely. For example, *amazement* was present in all the expectation studies to some extent, although not emphasized as a specific experience in reporting the results in the papers. Certain experiences – or aspects related to them – such as *meaningfulness*, *efficiency*, *intuitiveness* and *privacy* were much discussed more or less in all the studies. The amount of discussion around a category, however, necessarily does not indicate its criticality – rather, it can simply indicate the easiness for the participants to state opinions about it or, for example, being a much-discussed aspect in the public discourse on information technology. Hence, the magnitude, frequency or relative importance of the experiences cannot be stated based on such qualitative studies about expected, metaphorical UX.

The relations between service components and experience categories are presented in order to highlight the extent in influence each component can have and the complexity in which aspects an experience can originate from. These interrelations were not explicitly looked into in the studies but these are merely insights of the author, accumulated throughout the research process. In addition, based on expectations it is too early to specify how strongly each service component contributes to the experiences. For example, *amazement* can originate from various components that provide novelty value to the user but their relative strengths in doing so would depend also on the context of use, the current activity as well as the characteristics of the user. The following descriptions further explicate the given relations on a hypothetical level, thus illuminating possibilities for future research.

Augmentation can be considered as the principal origin of the experiences of *captivation*, *intuitiveness* and *awareness*. AR was expected to holistically bring out the digital content in the physical environment and provide the user with natural, multi-modal and immediate ways to interact with this content. Furthermore, the visual and pervasive interface of MAR can be seen to effectively catalyse, boost, or nourish the experiences of *empowerment*, *efficiency*, *liveliness*, and *tangibility* and, on the other hand, create new challenges for *privacy*. The general novelty value that AR has – and had when conducting the studies – can be considered to have created the expectations of experiencing *amazement*, *playfulness*, *inspiration* and *creativity*. With regard to social experiences, AR can be seen to catalyze them by providing an effective interface to browsing the location- and object-based socially constructed content and creating new content.

The **input and control** component can be seen to contribute especially to the interaction-related and sensory experiences of *intuitiveness*, *control*, *captivation* and *tangibility*. *Privacy* is affected by the input and control techniques in terms of social awkwardness of performing, for example, various gestures that were anticipated. Furthermore, *amazement* and *playfulness* can originate also from the input interaction techniques, especially if they demonstrate novelties or tangible interaction.

The component of **information embedding** can be seen as a central element for interaction-related experiences of *tangibility* and *intuitiveness*. More importantly, it is a universal and critical technical enabler for a wide range of experiences: *efficiency*, *empowerment*, *meaningfulness*, *awareness*, *liveliness*, *playfulness*, *inspiration* and *creativity*. Without the technology to integrate the digital content to physical objects and locations, the usefulness of AR would be very limited and many of the aforementioned

experiences could not take place in such a form as they were anticipated. Embedding is also a catalyst for the novel object- and location-based forms of *connectedness* and *collectivity*.

Community-created content is the main component behind *collectivity*. It can be expected to contribute especially to the emotional experiences of *liveliness* and *surprise* that are based on the amount and diversity of content in the service. *Trust* relates to the reliability and *meaningfulness* to the relevance of the socially constructed information. Such collective participation facilitates *awareness* and *motivation* with the help of the social layer, and can catalyze *playfulness* and *inspiration* to emerge over time.

Contextuality and personalization can be seen to contribute especially to the instrumental experiences of *efficiency* and *meaningfulness* through the higher relevance of the content. The flip side of personalization are the new challenges in terms of *privacy*: the service must have a lot of information about the user in order to personalization to take place. The contextuality and limited availability of extra mixed-reality services, e.g., based on a particular location, can create positive experiences of *surprise* and allow *inspiration* and new *motivation* to arise (e.g., innovating new ways of using MAR).

Proactivity would contribute especially to experiences of *surprise, increased awareness* and *empowerment*. Experience of *surprise* was often mentioned to originate from the situation where the information is received – i.e., the relevance and interestingness of a proactively prompted content in the current situation. The proactive features would support the becoming more and more *aware* of and curious towards the digital information related to familiar environments. *Empowerment* and *amazement* are partially also results of having proactive reminders and other automatic, unparalleled features available.

Finally, **mobility** can be seen as an overarching component behind all the other components, thus indirectly contributing to any of the experiences. However, it can be regarded to affect most the experiences of *privacy*, *control*, *trust*, and *connectedness*. These experience characteristics can be seen generic to almost any interactive technologies or Internet services where users create and acquire digital information and interact mediated by mobile technology.

5.2 Actual User Experience of First-Generation MAR Applications

The actual UX was approached with an extensive online survey whose results are reported in Papers **IV** and **V** and summarized regarding the methodology in Section 4.2.4. The following two sections summarize the results in terms of (1) the characteristics of highlight experiences created while using the applications (2) the qualities of the MAR applications with regard to UX. This is preceded by a short introduction about to which existing applications the results apply.

Table 4 reports the applications that were used among the survey respondents. Image recognition based applications focusing on product information, such as ShopSavvy and Stickybits, had been used less, especially as the primary application. The 'others' category included a diverse set of applications, from other camera-based utility-oriented AR browsers like SekaiCamera, to map-based AR (e.g., FlightRadar24Pro), 3D augmentation (e.g., Argon), shopping-related (e.g., pic2shop, shopsavvy), AR gaming (Kafkara, Pandemica), and translation applications (WordLens). Most of the respondents had been using several applications: on average, 2.8 different applications.

Table 4. Number of respondents (1) who reported to have used the particular application and (2) who selected it as their most used application.

Application	# have used	# selected as most used	Application	# have used	# selected as most used
Layar	69	35	ShopSavvy	11	0
Google Goggles	66	22	StickyBits	9	1
Wikitude	49	4	Sekai Camera	3	0
Junaio	44	16	Others	34	9
Nokia Point & Find	9	1			

As reported in Paper **IV**, the actual experiences were mostly based on usage over at least three months of time and the frequency of use being daily or weekly. Despite the recency of the applications, the respondents had clearly been using them rather actively. Regarding adoption of the applications, curiosity and the novelty value of AR were identified as the main motivators for installing them. Similarly, the continued use was also found to be mainly motivated by interest in the specific field of technology and its novelty value.

5.2.1 Most Satisfying and Unsatisfying Highlight Experiences

The participants' narratives of their most satisfying and unsatisfying experiences were approached with qualitative content analysis where the expectation categories were partially utilized in labeling the categories in final phases of the analysis. In the following, the naming and ordering of the categories is more or less according to the expected experience categories to allow identifying the main differences between the expected and actual experiences (see Section 6.1). Overall, the participants' descriptions contained much variety in terms of length of the description, what kind of experiences had been present, and how recent they were. Table 5 summarizes the types of both satisfying and unsatisfying experiences, which are reported in more detail in Paper **V**.

Overall, the satisfying experiences contain a rather good variety with regard to the type of experience. Most narratives reported pragmatic and instrumental aspects of *efficiency* in information acquisition, *empowerment* by having novel instruments and ways for utilizing information, and *awareness* of the digital content related to one's immediate surroundings. Emotionally focused experiences like *fascination*, *general pleasure* and *surprise* were also highlighted in several narratives. Other types of experiences, such as *immersion* in the mixed reality, and *social* experiences were clearly less frequent in the data. The descriptions of unsatisfying experiences, on the other hand, mostly focus on different grades of instrumental dissatisfaction and the relating emotion of frustration.

As with the expected experiences, many of the identified actual experiences are rather generic by nature, meaning that the particularities of AR as such had affected them rather little. Instead, most of the satisfying experiences were largely resulting from content and features being location-based, and the resulting utility value in ad hoc information needs in mobile contexts. The interaction and interface that are particular to MAR seem to have contributed mostly to the experiences of *awareness* and *immersion*. In addition, the charm of novelty in the interaction metaphor, as well as the new functionalities, mostly explains the emotional experiences of *fascination* and *surprize*.

The unsatisfied experiences seemed to result mainly from inadequate performance, hardware deficiencies, bad usability, unsuitable content, or instrumental expectations not being met. Because of especially the critical, yet mostly easily remediable functionality and usability issues, the more experiential challenges like lack of privacy or inspiration would not become emphasized. Regarding experiences of disappointment, it seems that the users' subjective descriptions of the experiences easily became strongly emotionally slanted and the other experiential components were given less significance. Overall, the diversity of the unsatisfying experiences is narrower than that of satisfying experiences – perhaps partially because of the emphasis on general disappointment and dissatisfaction.

Table 5. Summary of the most satisfying and most unsatisfying experiences (no. of narratives).

Experience characteristic	Description	Aspects contributing to the experience
Satisfying Experiences		
Efficiency (16)	Sense of efficiency in acquisition of location-based information, feeling helped by technology, saving time, money and effort	Easiness and instantness of interaction, location-based content, usefulness in general
Empowerment (26)	Feeling of powerfulness and being offered novel functionalities and tools for creating, finding and utilizing information, being able to do something not possible before	Utility value, relevance of location-based content, novelty values in interaction, collectively created content, ease of use
Awareness (27)	Being educated about one's immediate surroundings and finding novel aspects even in already familiar environments	Utility value, merging of realities, location-based content
Fascination (23)	Positive excitement varying in strength from general interest to amazement and wow effect, feeling of using something magical and 'cool'	Novelties in interaction and functionality, esp. first-time use, potential in commercializing AR
General pleasure (14)	Neutral pleasure or gratitude, being helped by or able to help others with the application	Interestingness of the content, utility value, ease of interaction
Immersion (3)	Being surrounded by a virtual world, the realism of the virtual, seeing 3D objects in real-world space	Novelties in interaction, esp. mixing realities
Surprise (17)	Finding useful or relevant content, the application performing better or more reliably than expected	Type and amount of content, functionality in general
Social (7)	Real time collaboration, remote social connectedness, shared experience in situ, showing off to others with the application	The social context, collectively created content, novelty value
Unsatisfying Experiences		
Disappointment (27)	Instrumental disappointment from not being able to complete one's task or meeting goal-oriented expectations, not finding what was looking for	Functionality problems, too little or irrelevant content, uselessness of the application in general
Dissatisfaction (25)	Mild or mediocre emotional dissatisfaction from various limitations in the application	Uselessness, functionality and usability problems, poor overlay
Frustration (5)	Strong dissatisfaction and irritation, doing things in vain or having to repeat tasks	Software crashes, hardware deficiencies, no content available
Information overflow (2)	Being flooded with irrelevant and uninteresting information	Too much content with no relevance or with bad quality
Loneliness (3)	Lack of social features and users, feeling alone in the new reality, social unacceptance	Too little content or other users

In addition to these qualitative descriptions of highlight experiences, the survey involved subjective statements to measure the degree of which the participants saw the applications to have enabled them to do or experience something. Despite the above-mentioned emphasis on the technical deficiencies

and disappointments, the statements showed generally high agreement with the applications' instrumental value. Most participants saw that MAR applications had enabled them to view new perspectives on places or objects significantly or moderately better than earlier. Similarly, MAR had enabled acquiring relevant information in the right place and at right time, as well as accessing hard-to-find information and user-created content about certain places or objects. Overall, MAR was seen to have enabled developing a good conception of the information related to one's surroundings. However, being able to attach one's own views on places or objects or to develop a feeling of connectedness with other users of the application was not as much agreed with. The current MAR applications hardly served as tools for social interaction or building a user community around them. Furthermore, despite the generally positive evaluations, rather many responded that the applications had not helped with any of the aforementioned aspects or had even made these aspects worse than earlier. Such contradictory evaluations hence reflect the ambivalences in the perceived overall UX.

5.2.2 The Experiential Qualities of the Applications

Tables 6 and 7 summarize the application elements contributing to the experiences – from a perspective of perceived strengths and weaknesses consolidated from all the applications. Overall, the evaluations highlight a diverse set of positive and negative qualities of the applications in terms of UX. Many of these relate to the aspects that were central in the descriptions of most satisfying and unsatisfying experiences (e.g., need for relevance, lack of true utility value) but focus on the application qualities instead of the experience per se. Both the strengths and weaknesses are related mainly to the three main elements: content, functionality and interaction.

Table 6. Experiential qualities: summary of the perceived *strengths* of all the applications.

Application component	Strength aspect	Description
Content	*Rich and lively (25)*	High and constantly growing amount of content, large user base
	Relevant (6)	Contextual information in the right place and filtered based on user's specifications, having content in especially the user's area
Functionality and performance	*Specific features (9)*	E.g., multiple image recognition at the same time, well working recognition, inclusion of 3D content
	Versatility of features (10)	The great extent of functionalities, universality as a tool, can be demonstrated and utilized in various fields of business
	Relative advantage (7)	Being better than other applications allowing similar activities, technically more reliable
	Practical usefulness (4)	Usefulness and instrumental value, e.g., finding nearby content or solving a real problem in everyday life
Interaction and UI	*Ease of use (8)*	User-friendliness, straightforward to use, easy to learn
	Positive interaction experiences (12)	Fun to use, innovativeness and appeal, enriching the physical world, stimulation, accessing lots of information easily
	UI in general (14)	Good UI solutions, simple and intuitive UI, stimulating UI
Overall	*Quality in general (8)*	Overall goodness, sophisticated and good performance, better than other similar applications
	Potential for future (9)	Continuous development, showing promise as a concept
	Brand and social reasons (3)	Perceived assets resulting from the brand, trust in the company continuing development, the application having most users or being most talked about

Table 7. Experiential qualities: summary of the perceived *weaknesses* of all the applications.

Application component	Weakness aspect	Description
Content	*Irrelevant (4)*	Content not localized, hard to identify and find the personally interesting content, either too artistic or too commercial
	Too much or too little (18)	Excessive content in some areas or does not meet the expectations with so little content, lack of user-created content or users in general, not having a suitable amount of content
	Poor quality (1)	Bad reliability or visual quality, content not modifiable
Functionality and performance	*Imprecise and deficient functionality (13)*	Poor user positioning and geo-spatial accuracy, calibration problems, poorly overlayed content and mixed realities
	Instability (5)	Bugs and crashes, lack of stability, failing to operate
	Hardware deficiencies (5)	Bad GPS and compass, poor camera, requiring special hardware such as the newest smart phones and an internet connection
	Poor support (2)	Not available for all operating systems, development activities not supported well enough (e.g. bad documentation)
	Too limited functionality (11)	Lack of social features, no real use for them after the first amazement, not really AR, practically useless functions, inability to operate in all areas (e.g. indoors)
Interaction and UI	*Bad usability (17)*	Loading time and complexity in accessing content layers, inconsistent UI structures, lack of user feedback, hard to reach content, menu structures
	Inconvenient and unaesthetic UI (8)	Not convenient for information gathering, not intuitive, cheap UI
User-originated issues	*Requires special hardware (6)*	Requiring high-end smart phones with the necessary sensors, data transfer capabilities and good batteries
	No need (2)	No actual need for such applications, no utility value
	Lack of trust (2)	Lack of trust in the service provider (e.g., in terms of privacy)

Overall, it seems clear that the full potential of applying AR in end-user applications was seen not to have been reached. Rather many of the applications that the participants had used seemed still to be work-in-progress or underdeveloped as applications that offer information content related to locations or objects. Consequently, the perceived weaknesses, as well as the unsatisfying experiences, attributed mostly to lack and deficiency of functionalities, poor usability, and lack of relevant content. Consequently, it seems that the first-generation MAR applications are not on such a level of maturity that the applications could be used for their commodity value rather than the novelty value.

5.3 *MAR UX*: Framework of User Experience in MAR Services

The two previous sections summarize the most central empirical UX-related results of the thesis. Here, the various experience characteristics, expected service components and perceived qualities of current applications are visually summarized in a descriptive framework (Figure 12). Reflecting to literature about theory building by Dubin (1978), this framework (1) includes the framing of the area, (2) introduces the central concepts (experience characteristics, service components) in the area, and (3) defines the relations between the concepts to some extent. Such a descriptive framework allows (1) development of design implications for MAR services, (2) operationalization of evaluation measures, and (3) drawing research questions for future qualitative research and hypothesis for experiments.

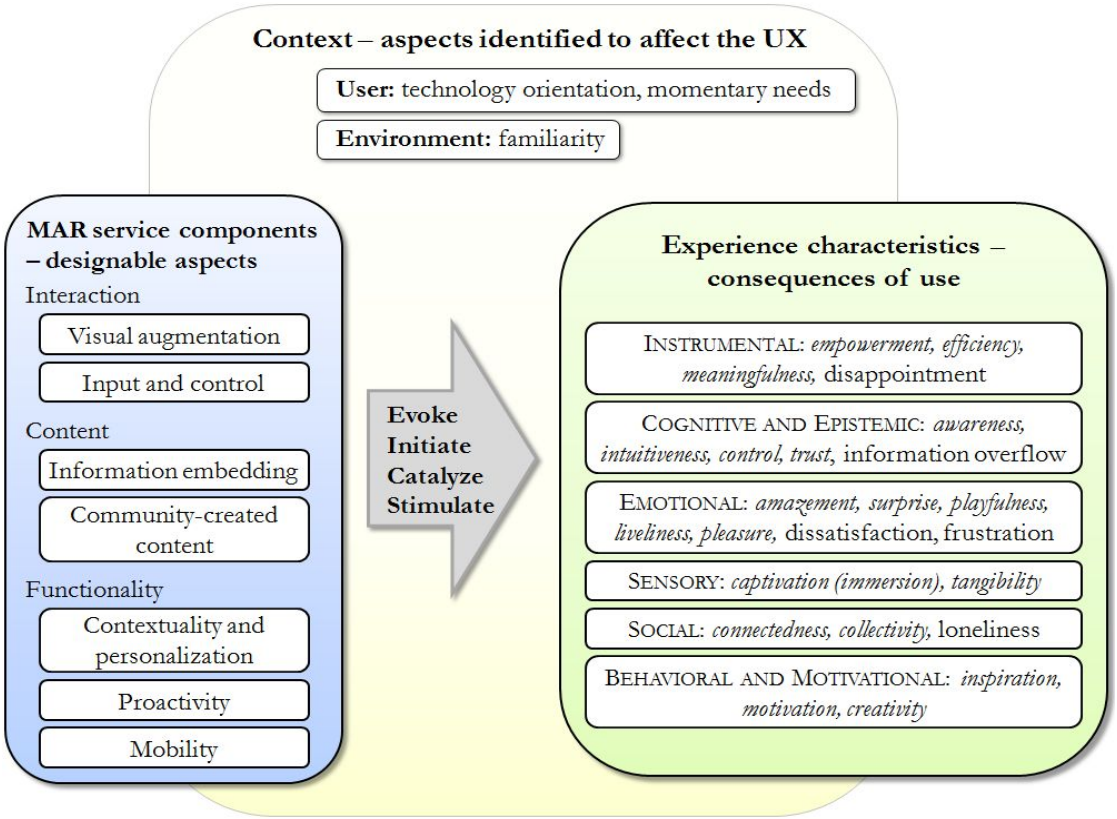

Figure 12. The MAR UX framework (inspired by Hassenzahl 2003, cf. Figure 3): a summary of the service components, the resulting characteristics of *desirable* (in *italics*) and undesirable experiences, and the contextual aspects identified to influence the UX.

Overall, the role of the framework is to summarize central theoretical concepts discussed in the previous sections. It serves as a basis for increasing theoretical understanding of the characteristics and possible sources of UX in the specific field of MAR, and hence drawing practical implications.

In addition to the categorization, the characteristics of experience can be roughly divided into (1) 'hygiene factor –experiences' and (2) 'stimulator experiences'. As pointed out in Section 2.5, usability is often considered as a 'hygiene factor': if it is missing, it probably causes dissatisfaction. Similarly, some of the experience characteristics above can be regarded to have a corresponding nature: the lack of it can cause dissatisfaction or other 'contra-experiences' (i.e., the negative side of the desired experience) but if present, the user might not even notice them. The experience of *meaningfulness* might not be perceived by the user until there is a lack of it, and 'contra-experiences' of frustration, anxiety or information overflow can be evoked because of bad service design in terms of personalization, relevance or user control. Similarly, *privacy* is a desirable experience that, when realized well, might not be perceived or bothered by the user but, when realized badly (e.g., social awkwardness or unwanted sharing of user's location), it disturbs the user and might strongly hinder other positive experiences or cause reluctance to use the service overall. *Trust* might be an unnoticed experience when the content and the service are trustworthy but 'contra-experiences' like distrust or disturbance can become relatively strong when the content is unreliable or out-of-date. Similarly, *intuitiveness* can also be seen as a 'hygiene factor experience' with a 'contra-experience' of, e.g., inconvenience. The flip side of *liveliness* and change of content over time is the unpredictability of the environment. As for *control*, it can

partially be seen as the 'contra-experience' of *captivation* or *surprise*: strong user control can hinder such immersive and technology-initiated experiences to evoke. Overall, the 'hygiene factor experiences' can be rather implicit and unconscious for the user, thus hard to be identified as specific experiences.

'Stimulator experiences', on the other hand, seem not to have such 'contra-experiences' based on these studies. The 'stimulator experiences' can stimulate, motivate, inspire or otherwise please the user and thus create explicit moments that users identify as "an experience": e.g., *surprise*, *amazement, playfulness, captivation, inspiration, motivation, creativity* or *awareness*. When there is a lack of a 'stimulator experience', it would not be perceived negatively. Instead, the use might simply feel conventional or dull at most. As shown also in the unsatisfying experiences reported in Paper **V**, the hygiene factors are often prerequisites for stimulator experiences to be present: oftentimes an efficient and usable performance creates experiences of general pleasure and allows evocation of 'stimulator experiences'. Finally, the experiences of *empowerment* and *efficiency* can be seen as slightly more generic as 'allowing novel activities' relates and contributes to many of the other desirable experience categories.

Regarding the context affecting the formation of experience, three central aspects were identified in the studies. In Paper **III**, the participants' technological orientation was found to affect the evaluations of the futuristic MAR scenarios in a statistically significant way. Highly technologically oriented people regarded the scenarios to be more appropriate and were more willing to try out the services than the less technologically oriented. This is a probable result of technologically oriented people putting much emphasis on novelty value of technology, and less technologically oriented assessing more the suitability and usefulness of the technology in their daily activities and needs. Furthermore, in Paper **I**, the familiarity of the environment seemed to affect especially the type of experiences that people expect, and thus also the relevance of information. In unfamiliar environments, pragmatic information needs about the ambient environment were more emphasized, whereas in familiar environments, emotional and stimulating aspects like surprise and creativity were expected to be important especially in long-term use. Additionally, the requirements and limitations for what information is considered relevant and desirable at each moment can depend much on the overall situation, the user's level of engagement with the service, her other activities, as well as her momentary needs for additional information in general.

In retrospect, the framework should not be considered as a 'model' that specifies interactions between the elements or accurate categorizations of experiences, or allows prediction of the actual UX in specific circumstances. The earlier sections discuss how the different service elements like AR as an output or information embedding as a functionality enabler are expected to contribute to especially certain experiences. However, with this empirical data, such interactions remain mostly on a hypothetical level, and hence it is important to consider the framework through its comprehensiveness rather than its details. Additionally, the framework is a qualitative consolidation that describes MAR services and applications in general, and not all parts of it are relevant in even all types of MAR applications. As shown in Paper **IV**, already the two main MAR application types of today (MAR-browsers and image recognition MAR) were evaluated differently.

6. Reflections and Practical Implications

This chapter discusses the meaning of the results from different theoretical standpoints and bridges the results to design and evaluation practices. Sections 6.1 and 6.2 contain rather academic discussion on the relation of expectations and actual experiences, as well as the results' relation to prior UX frameworks. Section 6.3 draws practical implications to practitioners aiming at designing rich experiences in MAR services. The second practical objective regarding methodology and subjective measures for evaluating experiential qualities with end users is extensively addressed in Paper **VI**.

6.1 Contrasts between Experiences and Expectations

The two-fold research question in the thesis allows discussing the similarities and differences between the (1) expected user experience and (2) the actual UX of first-generation MAR applications. The following contemplates this by highlighting the apparent differences between the resulted expectations and experiences, focusing on the characteristics of experience. This discussion is useful for (1) identifying experiential themes to be explored more in the current MAR applications and (2) further understanding the concept of expected UX in the sense of how realistic the expectations are. The qualitative approach, however, does not allow, e.g., making conclusions of to what extent expectations can predict actual experiences or the relative strengths of specific experience in the expectations vs. the actual experiences. After all, the comparison was not in the focus in determining the overall research approach. The expectations studies are based on inherent needs, expectations and attitudes of 'ideal' services, whereas the UX studies focused more on perceptions of applications that are only the first demonstrators of MAR as a technology.

Table 8. Contrasting expected and actualized experiences as identified in the qualitative data (negative experiences in parentheses). Expectations with no actualized counterparts are omitted to simplify the table (e.g., the expected motivational and behavioral experiences).

Experience class	**Expected**	**Actualized:** highlight experiences (Sect. 5.2.1)	**Actualized:** experiential qualities (strengths and weaknesses, Sect. 5.2.2)
Instrumental	*Empowerment*	Empowerment, General pleasure	Versatility of features, usefulness, potential for future
	Efficiency	Efficiency	Ease of use, (inconvenient UI, deficiencies in hardware and software)
	Meaningfulness	(information overflow)	Relevant/(irrelevant content, quality)
Cognitive and Epistemic	*Awareness*	Awareness	-
Emotional	*Amazement*	Fascination	Positive interaction experiences
	Surprise	Surprise	
	Liveliness	-	Lively and dynamic content
	-	(disappointment, frustration)	Brand-related assets
Sensory	*Captivation*	Immersion	-
	Tangibility	-	-
Social	*Connectedness*	Social, (loneliness)	-

Table 8 highlights the overall differences in the different types of experiences that were expected and that have actualized – either highlighted as the most (un)satisfying highlight experiences or mentioned in the evaluation of the applications' strengths and weaknesses (i.e., experiential qualities).

First, the instrumental experiences were emphasized in both the expectations and actualized experiences. In this regard, the actual experiences reflect expectations very well. *Empowerment* and *efficiency* were manifested not only in the most satisfying experiences but also as perceived strengths and weaknesses (e.g., empowerment via the potential of AR for future). Cognitive and epistemic experiences, however, were not present in the actual experiences apart from *awareness*. In addition, the qualitative data showed no evidence of experiences of *intuitiveness*, *control* or *trust* – neither as desirable experiences nor as contra-experiences, i.e., avoidable experiences.

Second, with regard to emotional experiences, there is rather much correspondence. *Amazement* was termed as fascination in the actual experiences but means more or less the same and was commonly mentioned. *Surprise* was present in two types: surprise arising from the content (as in expectations) and surprise arising from the application working better than expected (i.e., instrumental surprise). *Playfulness* and *liveliness* were not highlighted as critical incidents but the statements about overall UX in Paper **V** hint that the experiences are possible with the first-generation applications as well. In addition, the evaluation of actual experiences showed also a new aspect: brand-related assets probably were not concretized yet in the anticipated experience of a futuristic technology.

Third, sensory experinces are surprisingly under-represented in the actual experiences, and the same applies to social experiences. Such experiences after all relate to the hands-on interaction with MAR in a social environment and with socially constructed content. It seems that the high expectations related to *tangibility*, *captivation* and *collectivity* could not be properly realized with the current embodiment of MAR. *Captivation* was brought up as immersion by only a few participants and *connectedness* as general mentions about social experiences and, on the other hand, experiences of loneliness in the service. Additionally, *privacy* was not mentioned in either good or bad although it is often realized only after actually using an application for a while.

Finally, motivational and behavioral experiences did not show in the actual experiences in any form. The first-generation applications seem not to have been capable of serving as sources of behavioral *inspiration*, *motivation* or *creativity* – perhaps because of the rather simple augmentations, limited interactivity or lack of proactive features.

Overall, the first-generation MAR applications seem not to fulfill the high expectations of the potential users. Based on this data, the applications seem not yet to have been capable of, for example:

- Encouraging the users to be creative and artistic, to appropriate the applications in new ways, or to motivate them to participate
- Creating a sense of user community and belongingness
- Evoking feelings of concreteness and coherence of environment-related content, and presence and unity with the surroundings

At the same time, this gives much space and potential for considering such aspects in designing future services around MAR technology. The participants' evaluation of current applications clearly

focused on more practical and concrete aspects, such as general ease of use and practical usefulness. Especially the perceived weaknesses highlight simple deficiencies in technology that would need to be ameliorated above all else, which perhaps had inhibited the more complex positive experiences like inspiration and creativity to arise.

The explanations for the differences can be manifold. First, a large part of the expectations were very positively colored desires, which sets high standards for the actual perceived performance, usability, experiential value, and other quality attributes. It seems that the expectations were not met in the first-generation MAR applications – perhaps they simply do not correspond with the ideal that MAR can create in people as expectations. At least they are not as versatile in functionality and content as those MAR services envisioned in the expectation studies. Second, the research setup was not ideal for such comparison. A more controlled and experimental approach with validated quantitative measures would have been required for objectively credible comparison. For example, the participants were different in the expectation studies vs. experience studies, the interview or survey questions were slightly different, and the methods varied from interviewing to online surveys. Furthermore, the actual experiences were mainly gathered with descriptions of the most critical highlight experiences. Therefore, especially the most unsatisfying experiences focused on instrumental dissatisfaction, and other, less critical, experiences could not be highlighted in the limited number of narratives. Third, categories of expected experience like intuitiveness, playfulness and inspiration are fundamentally perhaps too implicit (i.e., 'hygiene factors') or unimportant for a user to identify them in the first place or to consider them important enough to highlight as a single most (un)satisfying experience. Such methodological effects are further reflected on in Discussion (Section 7.1).

6.2 Contrasting the Results with General UX Frameworks

As defined in Chapter 4, the experiences focused on in this thesis are meaningful, processed and conscious. The consequences of this focusing and the overall spectrum of the expected experiences become visible when contrasting the expectations to UX frameworks that discuss different facets of the concept of UX. This analysis helps further understanding the scope and nature of the experiences that were highlighted already in the anticipation phase regarding the emerging technology of MAR.

- Some of the expected experiences are clearly *user experiences* (e.g., *efficiency*, *awareness* and *captivation*) but some are more general human experiences or needs that are mediated by or indirectly created by using MAR services (e.g., *creativity*, *connectedness* and *playfulness*).
- Of the four threads of the holistic experience (Wright et al. 2008), these experience categories mostly represent *emotional* (i.e., judgments of how important MAR services would be with respect to one's needs and desires) but also *compositional* threads (e.g., *control*) and *sensual* threads (e.g., *captivation*) are present.
- Concerning Jordan's framework of product pleasure (2002), the expected experiences mostly manifest *psycho-pleasure (*both emotional and mind-related). Naturally, the aspect of *socio-pleasure* is present in the social experiences. However, *physio-pleasure* (related to body and senses) and *ideo-pleasure* (related to values and attitudes) are very little represented in the expectations.

- Most of the categories of expected experience are described on the *episodic* level of time span (i.e., "an experience" according to Forlizzi & Ford 2000). The different experiences probably also vary in length as well as strength. The *cumulative* level is present especially in the experiences of *awareness, trust, liveliness*, *collectivity*, *inspiration*, and *motivation*; they are something that probably would require a longer use of the service to appear.
- Considering the three levels of interaction by Forlizzi and Battarbee (2004), the expected experiences represent mostly *cognitive* interactions that focus consciously on the interaction at hand and result in knowledge (e.g., *awareness*), but also *expressive*, i.e., interactions that help users form a relationship to the product (e.g., personalization).

Overall, although the intentional focusing on meaningful, processed and conscious experiences probably has limited the extent, the expected experiences show good variety also in this light. In addition to such general contrasting, the relation of each category of expected experience to certain theories can be discussed in detail. Table 9 maps the categories to two well-known frameworks: (1) Hassenzahl's (2003) product-centered framework of perceived product qualities, and (2) ten central human needs by Sheldon et al. (2001) as a human-centered framework that illuminates the experiences in terms of what fundamental needs they represent. These can be seen as different components of experience that each of the categories of expected experience *mostly* represent or relate to.

Table 9. Mapping the expected UX characteristics to Hassenzahl's (2003) product-centered framework of UX and the categories of human needs by Sheldon et al. (2001).

MAR Experience characteristic	Hassenzahl's (2003) perceived product qualities	Sheldon et al. (2001): ten central human needs
Empowerment	Pragmatic (utility), Stimulation	Competence, Self-actualization
Efficiency	Pragmatic (utility, usability)	Competence
Meaningfulness	Pragmatic (utility, controllability), Stimulation	Competence, Autonomy, Self-actualization
Awareness	Stimulation, Evocation	Pleasure-stimulation, Competence
Intuitiveness	Pragmatic (usability, controllability)	Competence
Control	Pragmatic (controllability, usability)	Autonomy, Security
Trust	Pragmatic (controllability)	Security
Amazement	Stimulation, Pragmatic (utility)	Pleasure-stimulation
Surprise	Stimulation, Evocation	Pleasure-stimulation
Playfulness	Stimulation, Evocation	Pleasure-stimulation
Liveliness	Stimulation, Evocation, Identification	Relatedness, Pleasure-stimulation
Captivation	Stimulation, Pragmatic (controllability)	Pleasure-stimulation
Tangibility	Stimulation	Pleasure-stimulation
Connectedness	Identification, Stimulation	Relatedness
Collectivity	Identification, Pragmatic (utility)	Relatedness, Influence
Privacy	Pragmatic (controllability, usability), Identification	Competence, Security
Inspiration	Stimulation, Pragmatic (controllability)	Self-actualization, Pleasure-stimulation
Motivation	Stimulation, Pragmatic (utility)	Self-actualization, Autonomy, Pleasure-stimulation
Creativity	Stimulation, Identification, Pragmatic (controllability)	Competence, Self-actualization, Pleasure-stimulation

Considering the framework by Hassenzahl (2003) we can see that the characteristics of expected experiences cover both hedonic (stimulation, identification, evocation) and pragmatic product qualities rather extensively. Because of the slight overlap between this framework and the categorization of the expected experiences, pragmatic aspects are related especially to the instrumental experiences and cognitive and epistemic experiences. Stimulation, on the other hand, seems to relate to more or less all of the six experience classes but is most emphasized in emotional experiences like *amazement* and *surprise*, motivational and behavioral experiences like *inspiration* and *creativity*, and sensory experiences like *captivation*. Identification is seen to relate primarily to social experiences as well as *creativity* (in terms of self-expression). Finally, evocation relates to mostly emotional experiences but could perhaps not be considered as the *primary* aspect behind these or any of the other expected experiences.

Regarding the ten psychological needs by Sheldon et al. (2001) the variation is smaller. Competence and pleasure-stimulation seem to be much present in especially instrumental and emotional experiences, respectively, but are frequent also in other categories. Self-actualization rather naturally relates mostly to motivational and behavioral experiences, and relatedness to social experiences. After a few additional references to security, autonomy and influence, there are several basic needs that seem not to relate to any of the experience categories: money-luxury, physical-bodily, self-esteem. It seems that such needs either could not be envisioned in studies about expectations or are not relevant in the use of MAR – or any interactive technology.

The possibility of irrelevance of certain needs is consolidated by the findings of Wiklund-Engblom et al. (2009) who mapped six of the needs to people's experience descriptions about technology and media use. Autonomy was shown to link to, for example, experiences about flexibility, freedom of choice and expression of own opinions. Relatedness is linked to, e.g., communication and sharing-related experiences. Competence was found to map mostly with experiences related to usability, novelty, mastery and knowledge, and stimulation with social, cognitive, emotional, and creativity. Finally, influence showed relation to, e.g., connectedness and security to reliability, satisfaction and familiarity. Overall, this analysis indicates that especially satisfying experiences can be analysed and categorized according to underlying needs. Certain needs are more central in use of MAR – or technology in general – and, on the other hand, perhaps people simply do not want to express their needs related to some aspects or are not able to identify or verbalize them.

With regard to *actual* experiences, Section 6.1 discussed the contrasts to the expected experiences and highlighted the narrower breadth in the different characteristics of experiences. To continue this with speculation, there are other types of experiences that could be assumed to be present in the actual interaction with MAR and long-term use of the applications for actual needs, but were not. Considering the UX literature, the ideal of MAR as a vision, and the characteristics of interacting with MAR (Section 3.2.4), especially the following could have been present:

- Experiences of space and self-presence ("here and now" presence is much discussed in literature; e.g., Wagner et al. 2009) – resulting from, e.g., the egocentric point of view, tangibility of the interaction, visually comprehensive interface and mixing of realities

- Aesthetic experiences and appeal (Wright et al. 2008) – especially as a result of the visually pervasive and lively interface, and its rich sensorial output to the user
- Symbolic experiences and experiences of meaning (e.g., personal associations, social status, luxury; Desmet & Hekkert 2007) – because of long-term use of an interesting technology that is possibly socially awe-inspiring and the user's attachment to it in daily information acquisition activities
- Expressive interactions and experiences related to that (e.g., personalization, self-expression through the application, appropriation for new purposes) – resulting from the visual and egocentric interaction, frequent use, and social elements in the user community

As with expected experiences, the non-existence of such aspects in the data probably result from both methodological issues and the frailty of the applications in terms of user experience. As the actual experiences were gathered in merely one online survey with the critical incident technique, experiences of low meaning probably were overrun with more meaningful and critical experiences in the participants' experience descriptions. For example, perhaps presence and other space-related experiences actually have been evoked but they were not important enough to be highlighted instead of stronger experiences like fascination or surprise. The subjective statements in Papers **IV** and **V** also indicated that the diversity of experiences with MAR has indeed been more extensive, but some types of experiences simply were not highlighted in the CIT. Nevertheless, it is surprising that especially aesthetic experiences and the more long-term experiences (e.g., personal associations) were non-existent or merely marginal – and actually both in the actual experiences and the expectations. After all, they are often emphasized as important aspects of UX, as discussed in Chapter 2.

6.3 Design Implications

This section addresses the first practical research objective of concretizing the empirical results into design implications and principles with varying levels of abstraction. The previous sections' descriptions of expected experience can be used as general inspiration and design targets in design of future MAR service concepts as well as in refining existing applications. This section further bridges the gap between empirical research results and design practices of MAR by suggesting a number of general UX design principles as well as implications relating to interaction with and content of MAR. It is noteworthy that these are based on the researchers' own insights and understanding of what is relevant to design of MAR services. In qualitative user research like this, drawing practical design implications from the resulted in-depth and extensive understanding is often most efficient when the utilizers aim to comprehend the richness of the qualitative data themselves (Dourish 2006) and try to make their own practical conclusions relevant to the current design case – rather than to follow very concrete and detailed guidelines formed by only one researcher. Consequently, and because of the fact that the implications have not yet been used in actual design cases, the following implications should not be taken as validated guidelines but, rather, as insights from which to draw inspiration.

6.3.1 General Principles on Designing for User Experience in MAR

To start with, the following provides a set of general implications (or *principles*) that originate from both the empirical results of this thesis and the general UX theories presented in Chapter 2 contextualized to MAR services. These can help design especially in the early phases of concept design and ideating the service's scope, target users and target contexts of use. These six principles comprise a unity but each of them can also be used separately to remind of a particular aspect.

(1) **Consider users' expectations as starting points for the design**. The characteristics of expected experience can be used to consider 'how could this service make the user feel'. In early concepting phases, the design can be instigated by taking, for example, 2-3 categories as stimuli for brainstorming. These can vary in terms of how well they seem to fit together or what kind of contradictions can be formed: e.g., well fitting combinations like *surprise* & *inspiration* & *awareness*, *amazement* & *captivation* & *empowerment*, *collectivity* & *liveliness* & *creativity*, and more challenging combinations like *efficiency* & *captivation* or *privacy* & *liveliness*. In addition, the underlying values and needs why people would use MAR can be considered (e.g., needs to be competent, express oneself, or find relevant information to help completing a task).

(2) **Select the target experience categories based on the type of the service**. Consider which 'hygiene factor –experiences' are the most central requirements in the context of the service, and which experiences could be used as targets as 'stimulators'. Consider the possible 'contra-experience' that can be evoked if the experiential target is not reached. One aspect in the service type is the continuity of interaction. For example, *captivation*, *meaningfulness* and *awareness* can be seen more important in continuous AR interaction with MAR browsers than in sporadic use of object-based interaction. Alternatively, in gaming-related and other pleasure-oriented MAR services, the emotional, sensory, social, and motivational and behavioral experiences could be experimented rather freely.

(3) **Design comprehensively for the MAR-experience**. The formation of specific target experiences should be considered through all the service components – accessed content, presentation of AR, functionalities, interaction with AR etc. Similarly, consider how a specific experience can be manifested in other facets of UX (e.g., what could be the emotional or sensory component of a primarily instrumental experience). For example, AR as an output metaphor affects many experiential facets: the emotional by adding fascination, the epistemic by adding intuitivity and easy-to-understand interactions, and the sensory by allowing effortless but rich interaction. Overall, when designing for UX, the subjectivity and uncertainty grows, and hence the variation in interpretation and value formation grows.

(4) **Apply elements from other fields to MAR**. Potential users were found to see MAR services as holistic entities that can include, besides AR, various technological elements and interactions. In addition to utilizing the users' expectations as a starting point, various technological visions and possible design guidelines related to, e.g., IoT, AmI and smart environments could be considered to gain additional insight and inspiration for design. Furthermore, as many of the expected experiences are valid also in other fields, it can be

worthwhile to draw from such alternative instances of the experience. For example, playful experiences in games can arise from positive challenges, competition, thrill, humour or fantasy, which all could be applied to MAR as well.

(5) **Consider the role of context in facilitating experiences**. In interaction with mobile and ubiquitous services, the context of use can afford various desirable stimulator experiences (e.g., surprise or creativity arising from the social context). Similarly, negative experiences due to the context (e.g., lack of location-based content) can become attributed as the service's weakness. This contextuality would benefit from proactively notifying the user when there is a lot of content to be browsed or other users near by. In addition, until AR becomes a paradigmatic technology like the Internet, the users need to be reminded of its availability.

(6) **Support long-term engament and appropriation**. Consider how the experience could evolve and different experiences change relevance over time – as results of community-based sense making and the user changing in terms of moods, values etc. As personal meanings and relationship with a service become increasingly important in the long run, the service should support creation of meaningful experiences through creative use and personalization of MAR services. Such appropriation can allow new 'stimulator experiences' to emerge but needs also compelling ways to teach and communicate the possibilities of MAR. For example, games can be used to demonstrate new types of uses for MAR because games are further in the adoption of innovations curve and people are familiar with them. Overall, when considering MAR as a novel platform for services, it has the potential to have as extensive an evolution as the Internet has had from a text-based communication tool to a multifaceted platform for social media, commerce, gaming and art – which all could take place with MAR as well.

6.3.2 Implications Related to MAR Content and Interaction

The following lists implications that are more detailed than the principles above and relate mainly to the MAR information content, and presentation of and interaction with it. In addition to guiding in the concept design phase, these considerations can help designing an experientially rich and pleasing visual user interface, information content and input/output interactions, as well as refining the existing applications in these regards. The individual implications are independent entities, and are listed below simply in an order that forms an easily digestable narration.

(1) **Design MAR for exploration, the joy of finding**. AR is a powerful medium to afford discovering new aspects of the world and even radically changing the perception of it. For example, MAR browsers could show content from several information sources at once, without the user having to preselect them, which could facilitate the creation of *surprise* and *inspiration*. In addition, the digital affordances in the environment can be efficiently communicated to the user with AR. It could be used as an interface to location- or object-based services or related online services (e.g., buying a movie ticket via a movie poster), hence bringing latent digital services more easily accessible and making them truly ubiquitous. Overall, MAR can be used to efficiently link to other domains, such as WWW, newspapers or

paper guidebooks, and provide novel links between various things and types of information – hence facilitating the joy of discovery.

(2) **Turn the casual, aimless browsing into an experience**, such as *playfulness*, *inspiration* or *creativity*. Simply browsing the AR can be desirable and create intriguing embodied interaction experiences without need for explicit input like button pressing. In addition, the browsing is often fragmented (e.g., a few minutes at a time while waiting for something). Such singular momentary experiences could be bridged to a unitary evolving interaction experience. For example, augmentations could be used to afford digital information related to not only currently surrounding things but also to places one only just passed.

(3) **Utilize the visual pervasiveness in browsing MAR**. In current MAR browsers, the POIs are often visualized on a horisontal line across the display, hence not utilizing the 3rd dimension (up – down). The different layers or sources of content could be placed on different heights on the AR view to allow displaying different types of content simultaneously and to help browsing and selecting objects. Cues like colours, animation, or haptic output could be utilized to emphasize, e.g., content that is new, created by friends, or otherwise considered important. Similarly, there should be sufficient visual cues indicating the accuracy of the augmentations: from object-specific augmentations to place- and area-specific. Overall, utilizing different visualizations of different types of content would help the user to more easily comprehend the extent of the surrounding digital information and perceive the momentarily most relevant information.

(4) **Promote the new mental model and metaphor**. Designing for experience in MAR is not only about creating useful services but also about changing the way people perceive reality and relate to it – i.e., changing their mental models. The mental model of AR should be 'smoothed reality' or 'interactive reality' instead of 'complexified reality' or 'crowded reality'. For example, compared to the metaphor of digital maps with POIs, AR perhaps loses in scalability but excels in 'in situ' relevance, captivation and tangibility, and in providing more versatile and interactive content. Educating people of the inherent strengths of MAR needs more hands-on guidance than what the current MAR applications provide. Otherwise, the MAR experience can stagnate on short-term amazement and not reach its true potential.

(5) **Allow efficient controlling of the realities**. The diversity of content sources in browsing becomes easily overwhelming. It should be easy to switch between the sources (e.g., simple tangible interactions like hand gestures) as well as to shut the augmentations off to restore the mere reality (e.g., by simply shaking the hand-held device). After all, the contexts change rapidly (e.g., number of people around) and so does the user's abilities to focus on AR along with the physical environment.

(6) **Embrace instantness**. Allow an instant view to the AR world when starting a MAR browser (i.e., not choosing the layers first etc.) Similarly, people are used to fast WWW-browsing and expect the content behind AR icons to be accessible instantly. The default AR view should be personalizable, e.g., by letting the user select what information is augmented besides the POI

icons (type of POI, rating, prices of products etc.). After all, the objects and places that can be augmented vary drastically in terms of what people want to know about them.

(7) **Consider the potential in augmenting the visual sense**. Moving forward from the current overlaying metaphor, future MAR development could focus on truly augmenting the human senses (e.g., infrared vision, night vision, superzoom, slowing things down, visualizing associations between objects, and tele-seeing, -hearing or -touching). Technical feasibility is perhaps far away but these would surely drive especially *empowerment*, *captivation* and *amazement*.

(8) **Design for in situ interactivity and tangibility of MAR content**. Current MAR applications focus on content consumption; they neither allow real-time content creation in situ nor modifying it (e.g., changing location, modifying the appereance, adding details). For example, MAR browsers could utilize interactions familiar from WWW browsing, such as bookmarking, having parallel sessions and browsing history, and rating and 'liking' content, which all would add up to liveliness. MAR could transmute static, passive content into interactive, e.g., with the help of animations, 3D and other aspects of realisticity. In addition, to increase tangibility and authenticity, the augmentations could be submitted to the laws of the real world, such as gravity, lighting, weather, objects not overlapping etc.

(9) **Fit the type of augmentation to the purpose**, i.e., from simple 2D overlay to highlighting objects in reality and adding precisely aligned 3D augmentations. Simple highlightings and 'floating' content can serve well in visualizing affordances whereas more precisely integrated and realistic AR is useful in detailed interaction with the AR objects or in changing the user's perception of a real object.

(10) **Support subjectivity and continuous modification of the relevance**. As MAR can be said to emphasize relevance more than online services, there should be efficient ways for users to flag irrelevant or bad-quality content and, more importantly, to adjust what type of content is shown. Various user modes could be set to balance between viewing only strictly relevant content and viewing a lively and possibly surprising AR environment.

(11) **Value the collectivity of content**. Content created by other service users was often enthroned as important source of *surprise* and *meaningfulness*. The trends in online services could be brought to AR as well, to add liveliness and social interaction: 'pinterest of MAR' or 'twitter of MAR' etc. MAR services could involve augmentations modified, enriched and supplemented by other users – both for entertainment and pragmatic purposes.

All in all, the implications and principles can provide a starting point for designing new MAR service concepts as well as refining existing ones. However, the entire diversity of the results is by no means covered in these principles, and, therefore, especially the descriptions of the categories of expected experience can offer further inspiration for design activities. These have not been developed by systematically brainstorming desing implications based on each experience category but, rather, represent such aspects that were considered important or novel enough to be presented in addition to the user research results and the resulted framework.

7. Discussion and Conclusions

This chapter sums up the thesis by summarizing the main empirical findings and the utility value of the MAR-UX framework and practical implications. This, however, is preceded by a discussion of the credibility of the research approach to understand the possible limitations and shortcomings. Finally, Section 7.3 suggests an agenda for future work of UX in MAR.

7.1 Methodological Discussion

The used methods and approach always have limitations and weaknesses that need to be highlighted to be able to assess the reliability, validity and value of the research and the drawn theoretical and practical conclusions. In qualitative research, the concept of *credibility* by Lincoln and Guba (1985) has been suggested to replace the concepts of internal and external validity that are mostly used in experimental and quantitative research. Credibility refers to the consistency and harmony of the conclusions and theorizations drawn from the empirical qualitative data. Furthermore, another aspect often evaluated in qualitative research is *ecological validity*, i.e., the degree to which the used methods, materials and setting of the study correspond to the real-life situation. In addition to the methodological reflection in all the thesis papers, the following sums up aspects of possible sources of bias and flaw that can be seen as the most significant in this research.

First, the *research setup* unavoidably caused some limitations for especially ecological validity. In the expectation studies, with such immature technology and little concrete examples provided, the participants can have found it challenging to picture the actual interaction and resulting experiences. Consequently, the expectations might change once they have become familiar with functional MAR services. To minimize bewilderment from a futuristic and intangible technology, the contexts, tasks and users in the scenarios were intended to be easy to relate to. The relatively short periods that the participants spent on the studies (approx. from 15 mins to 1.5 hours) probably did not allow them to ponder the asked matters thoroughly. This might have caused "lay functionalism", i.e., preferring practical aspects over hedonic, as discussed in Paper **II**. This probably partially explains also the high effect of the respondents' technological orientation in the online survey evaluation results; perhaps they based the evaluation on their general attitudes rather than thorough contemplation of MAR in particular. Furthermore, in this regard also the "halo effect", i.e., the attribution of good quality on one attribute positively influencing judgment on another, might have affected the results (Hartmann et al. 2007).

Second, with regard to the *user representatives*, the participants were mostly representing the Finnish culture. This might have affected what kind of expectations were expressed, the types of experiences people expected of MAR as a technology, and what aspects were considered to affect the overall UX. However, the statistical test between Finnish and other cultures did not show significant differences in Study 2, which implies that this is a minor issue and marginal compared to the effect of the participants' technological orientation. The focus on early adopter, on the other hand, was deliberate

as discussed in Chapter 4. However, in retrospect, we could have prescreened the participants of the expectations studies more carefully in order to have a more focused type of representatives of potential users, and thus allow generalizing the results at least to some extent in this group. Moreover, people often misjudge their level of technological orientation as well: for example, it is natural for people to agree with "trying products before others" (Dennis et al. 2009). Credibly measuring the 'technological orientation' is a challenge, which could not be addressed in this research. Additionally, we could have surveyed the participants' prior knowledge of the concept of MAR in order to control whether the stated expectations are based on the *initial perceptions* or more *long-term contemplation* of MAR. These aspects can be said to limit the ecological validity of the research but at the same time should not weaken the practical value as design inspiration. Overall, considering the inevitable sampling limitations in qualitative research, conclusions on the relative importances of different experience characteristics should not be made based on the reported numbers of answers.

Third, *studying people's expectations* contains particular limitations and minefields. Expectations are always bound to time (i.e., based on experiences of earlier technologies) and they are socially constructed: people anticipate things based on marketing, company brands, what other people talk about, and what others have experienced. The sources of expectations reported in this thesis can have been influenced by the participants' earlier experiences of interacting with the real world, mobile communication technology and other information systems like WWW or virtual worlds. The baseline of the participants' prior knowledge of MAR as a concept could not be consistently measured throughout the studies. In addition to the fact that measuring the familiarity with the various facets of MAR is very hard, the measuring activity itself would have affected how they perceive the new technology. Here, participants' general technology attitudes and orientation were considered more reliable measures and more relevant for the variation in the expectations. In retrospect, however, at least some open questions could have been asked from each participant in this regard, which could have helped in assessing how the expectations possibly varied based on the earlier knowledge. Furthermore, there probably exists a body of additional hidden factors that affect what and how people expect of new technologies in general – but have not been identified in the relatively scarce prior research about expectations.

Continuing on issues related to expectations, the responses are inevitably influenced by the examples indicated in the stimuli, such as scenarios and illustrations of MAR, and hindered by people's momentary interpretation of them. The variation in interpretation probably partially caused the wide coverage of what MAR services were seen to encompass. As this was expected, the focus was put on *casual and unscheduled activities*: they are easy to talk about and natural to attribute expectations on them because of their day-to-day frequency and existence of earlier habits. On the other hand, this also limited the scope of expectations that could be gathered, e.g., those stemming from work-related contexts, rural environments or situations while not on foot. The tone of presenting scenarios is another influencing factor. For example, scenarios in Study 3 tilted slightly towards presenting the possibilities of MAR rather than its risks, which probably explained the acceptance and positive expectations to some extent; rewriting the scenarios by emphasizing the inherent risks in them would

probably resulted in lower acceptance and elicited less desirable experiential targets. However, as the research focus was more on desirable experiences, the positive slant was considered justified.

Furthermore, earlier research on expectations mentions certain aspects to highlight. People often tend to expect their future experiences to be stronger and more ardent than the actual ones (Baumeister et al. 2007). Wilson and Gilbert (2005) highlight that people routinely mispredict the intensity and duration of their emotional reactions (e.g., pleasure or displeasure) to future events. Causes for this are people's tendency to underestimate the extent to which other events will influence thoughts and feelings, and to anticipate how quickly they will make sense of things that happen to them. Such aspects are hard to evade and hence important to identify as factors affecting the overall conclusions: the stated expectations are probably slightly exaggerated. Hence, not all the expectations might be such that when they are not met in a future service the user would get strongly disappointed. Additionally, the rapid evolution of the MAR field and mobile technology in general can make a snapshot of the expectations of a specific moment outdated after a while. For example, some needs brought out by the participants (in 2009) have already been addressed in today's MAR applications (e.g., translating texts as highlighted in paper **I**). In Ubicomp literature, Carter and Mankoff (2004) also highlight that expectations and perceptions evolve – in their case, regarding how to use displays and perceptions of privacy and usefulness.

Fourth, *theorization* of the elusive nature of expected UX in the multi-faceted field of MAR is undoubtedly challenging. The topic could have been investigated and presented from various angles and through disciplines like customer value, user acceptance or usability. The choice of focusing on UX is based on its novelty aspect as a theoretical background, as well as the recently understood importance of the emotional and experiential elements as quality factors in use of technology. However, this might have guided the analysis and narration to certain aspects while ignoring others, hence limiting the completeness of the framework. Furthermore, the perspective to expectations in the studies was kept wide by aiming to gather needs and desires, as well as requirements and presumptions. However, to create a uniform theoretical framework with usefulness for providing design targests, the focus in meta-analysis was on expectations related to desirable experiences. Doing this might have further diluted the richness in the gathered less positive expectations (e.g., minimum requirements and presumptions of undesirable features in the MAR services).

Considering the categorization of especially the expected experiences, neither the categories nor the upper-level classes are totally exclusive or unambiguous. For example, *captivation* can be seen to belong also to the classes of cognitive and emotional experiences, and to consist of several further detailed aspects. This can be seen unavoidable in qualitative theory building until the framework has been challenged with statistical tests and validation procedures. As discussed before, a theoretically waterproof categorization was neither the goal at this point of the research agenda. Furthermore, analysis and identification of categories is dependent on the inevitably subjectively coloured interpretation of the researchers. A researcher is always primed by their understanding of the world – in this case, about the types of experiences people can have – which might have limited the identification of the diversity of experiences. Strength in our approach in this sense is that especially in

Studies 1 and 2 the analysers were partially naïve to the related research of MAR and UX, which helped to approach the open coding in the analysis with as little assumptions as possible. Only in the late cross-analysis phases were relevant UX theories reconsidered and the six upper classes of the experiences were analysed according to an existing theory. Finally, measures of interrater reliability were successfully utilized in the analysis of actual experiences and this could have been done in regard to the expectations as well. On the other hand, this would have limited the collaborative approach in the data analysis (e.g., in building the affinity diagram), which was, again, seen as a very insightful approach for the analysis in especially the first studies in the intersection of MAR and UX.

7.2 Revisiting the Research Objectives and Contribution

To recapitulate, the research questions of the thesis concerned (1) the expectations of UX with MAR services and (2) the first actual experiences of first-generation MAR applications. In addition, practical objectives of providing design and evaluation implications were set. The research questions – here, 'what' questions – have been addressed mainly in Chapter 5, which culminates in the framework that describes the various expected and actualized experiences, as well as the service components contributing to UX. The following summarizes the findings related to the main research questions as well as a few additional academic lessons of the thesis:

- Potential users attribute a diverse extent of expectations to MAR services. The scope of expected experience characteristics ranges from generally well-known instrumental, emotional and sensory experiences to epistemic and behavioral experiences. End user's perception of a service entity is not limited by theoretical or technical definitions but driven by one's own needs and practices. For example, social experiences, community-created content or proactivity are perhaps not particular to MAR per se but were expected nevertheless. The coverage stands also in the light of prior UX frameworks, considering, e.g., the facets of experience categories, time span and underlying human needs. This boundlessness of expectations most probably applies also to other emerging technologies.
- The actualized experiences display a much narrower scope, mostly manifesting rather simple experiences of efficiency, surprise, fascination and disappointment. Hence, the current MAR applications can be said to be rather far from the ideal that the visions of AR have created as well as from the expectations that people have of it. The reasons for this underachievement seem to lie not only in technological deficiencies but also in lack of suitable content and various UI issues.
- When studying expectations, people seemed to perceive MAR very widely, the service entity consisting of not only the AR output metaphor but also components of input and control, information embedding, community-created content, contextuality and personalization, and proactivity. Additionally, visual AR as an output metaphor is expected to affect UX in many ways; it can, for example, facilitate, mediate or stimulate various experiences. However, the specific interrelations and causalities between the components and experiences remain as future research.

- Technological orientation was found to be an overarching and statistically significant factor in how positively people regard and expect aspects of MAR. It seems that users base their level of expectations largely on their general orientation and attitudes towards technology. Consequently, the design of early MAR services could indeed be targeted to early adopters in order to let them explore the technology and pinpoint the most naïve experiential issues before addressing the masses of consumers.
- The overall value and UX – especially in long-term – of MAR seems to be based on the richness, relevance and trustworthiness of the content rather than the functionalities or interaction techniques. MAR was often seen simply as a transparent interface to the intriguing information in the surroundings. In this sense, MAR competes with mobile web browsers and other LBS in acquiring surrounding digital information, and hence needs to focus on its strengths on providing high relevance and tangible, natural interactivity with the content.

Considering the topic on methodological and metatheoretical levels, the following conclusions can be drawn in the light of the methodological limitations in Section 7.1. Based on the practical implications presented earlier, it seems that *understanding people's expectations can indeed drive design and evaluation*. The expectations are partially even unrealistic and can be considered as 'ideals' on the framework by Teas (1993). Instead of limiting to merely the concept of MAR, the expectations were probably based on the participants' general needs and values, as well as their experiences of, for example, other location-based services and browsers of digital information. After all, the participants had no prior experience of MAR as a technology, MAR-based products or company brands in MAR business, which normally would affect the expectations to large extent. Nevertheless, such high expectations of early adopters can serve as an inspirational basis in various design phases and creating evaluation measures. Hence, it seems feasible and worthwhile to study people's expectations of their own subjective experience – not just the expectations of the product, its features or its price, as often focused in consumer research.

However, the expected UX as an anticipatory and metaphorical experience neither covers everything to be considered in design nor prognostigates the actual UX in detail. People's expectations seemed to ignore aspects that can be argued to be important in any MAR service but simply were not brought up. For example, aesthetics of the UI, pricing and brand aspects, and physical ergonomics and social acceptability of the interaction are undoubtedly important aspects that were not highlighted as expectations. Perhaps they are self-evident as quality attributes, and early adopters assume them to be automatically 'included' in any product. Consequently, researching expectations can be argued too intangible and to lack concreteness for participants to consider some, even critically important, aspects.

Carrying out *technology domain-specific* research on UX is challenging in terms of identification of experiences and issues that result particularly from the technology in question. Despite the focus on visual MAR in this thesis, the conceptual overlap in the Ubicomp-related technologies and the participants' broad-minded conceptualization of MAR caused the empirical research unavoidably to touch also, for example, AmI and context-awareness. People expected also such experiences that can

be said to be irrelevant to MAR as a new interaction metaphor (e.g., *connectivity* and *collectivity* that can be mediated by a diverse set of technologies). As the participants' expectations largely consisted of desires and wants, the results manifest abstract and general needs of people that could be attributed to many other emerging technologies as well: for example the experiences of *empowerment*, *efficiency*, *control*, *trust*, *privacy* (see, e.g., Iachello & Abowd 2005) and *intuitiveness*.

Studying technologies that people have no experience of seems to have an inherent challenge of lack of specificity in terms of what aspects are attributed to each particular facet of technology. Consequently, based on this research, it is premature to pinpoint in detail the differences between, for example, UX of mobile AR and UX of other kinds of AR – or UX of Ubicomp in general. Nevertheless, perhaps the most *mobile* AR -specific categories of expected experience can be said to be *meaningfulness* and *liveliness* (because of their centricity in current environments and activities where mobile devices are used) but, even so, they should not be valued more important characteristics or design targets than the other categories. The flip side of this lack of specificity is that this research can inspire research around UX more generally, e.g., related to LBS, AmI and IoT. The empirical results should not be generalized as such to other fields of technology or application areas but the theoretical concepts could be successfully *transferred* (Lincoln & Guba 1985) and applied to various contexts to inspire new research questions and design approaches.

Finally, the following recapitulates the contributions of this thesis.

- This research is highly topical because of the novelty of both the concept of UX and the field of MAR. With respect to prior research, uniqueness is exhibited not only through the contextualization of UX research in this emerging field of technology but also through the research focus on expected user experience.
- The resulting framework (i.e., a descriptive model) is a comprehensive synthesis with regard to the hybridization and consolidation of the various facets related to UX and MAR. The framework introduces and clarifies various concepts; it provides a common language, desirable design targets to utilize in service design, and aspects to consider in assessing the goodness of MAR services in terms of UX.
- The framework is concretized into design and evaluation implications. The design implications can help in the early concept design phase, in designing the visual user interface, as well as in designing and refining the information content and input/output metaphors of both future and current applications. The methodological implications culminate in the subjective measures for evaluating UX of MAR (Paper **VI**).

7.3 Future Directions

Such qualitative research pioneering on a novel area raises many questions to be asked in future research; research on the path of UX of MAR has only taken its first steps. The breakthrough of MAR still keeps the industry waiting for itself and the adoption pace of MAR is perhaps not as quick as anticipated some years ago. Truly remarkable demonstrations of the usefulness, instrumental value, and the experiential value are needed before the great majority of consumers get interested in it, as

well as the the much-anticipated revenues can be reached. The following highlights aspects that this thesis brought up to be studied and alternative approaches to be utilized in future empirical research of MAR and UX. The questions are mostly academic in nature but elaboration of these issues can further also the development of MAR services.

First, this 'snapshot' of potential users' expectations probably does not endure time as people's perceptions and expectations of MAR evolve along the overall technological development. It would be interesting for not only MAR but also emerging technologies in general to see how people's expectations evolve over time and what the reasons are for this. Additionally, the actual experiences could be researched also in the context of other types of MAR applications, such as AR in print media, AR installations and AR in entertainment. Here, the research focus could perhaps be more easily put on the idea of augmenting the image of the real world, which after all can be expected to change how people comprehend their surroundings and define ubiquitous technologies.

Second, after this initial understanding of the spectrum of expected – and partially also actual – experience of MAR, a more extensive empirical data could allow refining the descriptive framework into more reliable one and even into models that describe validated interrelations of concepts and allow prediction of the actual experience to some extent. A validation of the framework would also allow development of a more comprehensive set of detailed and validated evaluation measurements. An apparent next step in this regard is to operationalize also those categories of experience not included in Paper **VI**. Similarly, the concept and understanding of 'contra-experiences' could be used to create, for example, statements with conceptual polarities (i.e., semantic differential) instead of the Likert-agreement scale.

Third, in addition to continuing the qualitative approach as above, the MAR-UX research agenda would benefit from additional approaches, especially controlled experimental and statistical ones. This would afford to research, for example, cultural and other background-based differences in potential users, the effects of specific design solutions, or the effects of the pervasive MAR metaphor to specific experiences in a way that enables also statistical conclusions to be made. In the long run, this is central to maintain the credibility of the theorizations as well as the field of UX in general. Especially the differences in cultures and personal traits can be expected to play a high role in how anticipations form and how they affect actual use. The experiences and needs might not differ that much between cultures (cf. Sheldon et al. 2001), but the relational salience of the experiences or the design solutions contributing to them might do so. Furthermore, an interesting research topic is how the relationship to technology, its role and long-term UX change because of such a technology with many profound novelties in interaction metaphors and functionalities.

Finally, existing general theories and measurement models like those belonging to technology acceptance or product value could be utilized to allow, e.g., comparing MAR with other fields of technology in the light of these theories. Such theories could also help understanding on what elements people establish their expectations as well as help developing methods for reliably assessing the influences of specific technologies or solutions on people's activities and experiences.

References

Aittala M (2010) Inverse lighting and photorealistic rendering for augmented reality. *The Visual Computer* 26(6-8):669-678.

Alasuutari P (1993) *Laadullinen tutkimus*. Vastapaino: Tampere.

Allen M, Regenbrecht H, Abbott M (2011) Smart-phone augmented reality for public participation in urban planning. Proceedings of OZCHI'11. ACM Press, pp. 11-20.

Anastassova M, Mégard C, Burkhardt J-M (2007) Prototype evaluation and user-needs analysis in the early design of emerging technologies. Proceedings of HCI'07 (LNCS, vol. 4550). Springer, pp. 383-392.

Arhippainen L (2009) Studying user experience: issues and problems of mobile service – Case Adamos: user experience (im)possible to catch? Doctoral dissertation, University of Oulu.

Arhippainen L and Tähti M (2003) Empirical evaluation of user experience in two adaptive mobile application prototypes. Proceedings of MUM'03. ACM Press, pp. 27-34.

Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. *Computer Networks* 54(15):2787-2805.

Avery B, Piekarski W, Warren J, Thomas BH (2006) Evaluation of user satisfaction and learnability for outdoor augmented reality gaming. Proceedings of AUIC'06. Australian Computer Society Inc. 8p.

Azuma RT (1993) Tracking requirements for augmented reality. *Communications of the ACM* 36(7):50-51.

Azuma RT (1997) A survey of augmented reality. *Presence: Teleoperators and Virtual Environments* 6(4):355-385.

Azuma RT, Baillot Y, Behringer R, Feiner S, Julier S, MacIntyre B (2001) Recent advances in augmented reality. *IEEE Computer Graphics and Applications* 21(6):34-47.

Azuma RT and Furmanski C (2003) Evaluating label placement for augmented reality view management. Proceedings of ISMAR'03. IEEE, pp. 66-75.

Bach C and Scapin D (2004) Obstacles and perspectives for evaluating mixed reality systems' usability. IUI-CADUI workshop on exploring the design and engineering of mixed reality systems (MIXER).

Baillot Y, Brown D, Julier S (2001) Authoring of physical models using mobile computers. Proceedings of ISWC'01. IEEE, pp. 39-46.

Bane R and Höllerer T (2004) Interactive tools for virtual X-ray vision in mobile augmented reality. Proceedings of ISMAR'04. IEEE, pp. 231-239.

Barba E, MacIntyre B, Rouse R, Bolter J (2010) Thinking inside the box: making meaning in a handheld AR experience. Proceedings of ISMAR'10, Seoul, Korea, IEEE, pp. 19-26.

Bargas-Avila JA and Hornbæk K (2011) Old wine in new bottles of novel challenges: a critical analysis of empirical studies of user experience. Proceedings of CHI'11. ACM Press, pp. 2689-2698.

Battarbee K (2004) Co-experience: Understanding user experiences in social interaction. Doctoral dissertation, University of Art and Design, Helsinki.

Baumeister RF, Vohs KD, DeWall CN, Zhang L (2007) How emotion shapes behavior: feedback, anticipation, and reflection, rather than direct causation. *Personality and Social Psychology Review* 11(2):167-203.

Beyer H and Holtzblatt K (1998) *Contextual design. Defining customer systems*. Morgan Kaufmann, 496p.

Bhattacherjee A (2001) Understanding information systems continuance: an expectation–confirmation model. *MIS Quarterly* 25(3):351-370.

Billinghurst M and Kato H (2002) Collaborative augmented reality. *Communications of the ACM* 45(7):64-70.

Billinghurst M, Grasset R, Seichter H, Dünser A (2009) Towards ambient augmented reality with tangible interfaces. Proceedings of HCII'09 (LNCS, vol. 5612). Springer, pp. 387-396.

Billinghurst M, Kato H, Myojin S (2009) Advanced interaction techniques for augmented reality applications. Proceedings of VMR'09. Springer-Verlag, pp. 13-22.

Bimber O and Raskar R (2006) Modern approaches to augmented reality. Proceedings of SIGGRAPH'06 courses. ACM Press.

Blythe MA, Overbeeke K, Monk F, Wright PC (2003) *Funology: From Usability to Enjoyment*. Kluwer Academic Publishers: Netherlands, 295p.

Bowman D, Gabbard J, Hix DA (2002) A survey of usability in virtual environments: classification and comparison of methods. *Presence: Teleoperators and Virtual Environments* 11(4):404-424.

Boztepe S (2007) User value: competing theories and models. *International Journal of Design* 1(2):55-63.

Buccini M and Padovani S (2007) Typology of experiences. Proceedings of DPPI'07. ACM Press, pp. 495-504.

Carter S and Mankoff J (2004) Challenges for ubicomp evaluation. Technical report of University of California, Berkeley, no. UCB/CSD-04-1331, June 2004. Available: http://www.eecs.berkeley.edu/Pubs/TechRpts/2004/5538.html.

Castells M (2000) *The rise of the network society, the information age: economy, society and culture Vol. I*. Blackwell.

Caudell TP and Mizell DW (1992) Augmented reality: an application of heads-up display technology to manual manufacturing processes. Proceedings of HICSS'92. IEEE, pp. 659-669.

Cheok AD, Yang X, Ying ZZ, Billinghurst M, Kato H (2002) Touch-space: mixed reality game space based on ubiquitous, tangible, and social computing. *Personal and Ubiquitous Computing* 6(5-6):430-442.

Cheok AD, Goh KH, Liu W, Farbiz F, Fong SW, Teo SL, et al. (2004) Human pacman: a mobile, wide-area entertainment system based on physical, social, and ubiquitous computing. *Personal and Ubiquitous Computing* 8(2):71-81.

Chitturi R, Raghunathan R, Mahajan V (2008) Delight by design: the role of hedonic versus utilitarian benefits. *Journal of Marketing* 72(3):48-63.

Choi J and Kim GJ (2012) Usability of one-handed interaction methods for handheld projection-based augmented reality. *Personal and Ubiquitous Computing* 2012.

Clarkson PJ (2008) Human capability and product design. In: Schifferstein HNJ & Hekkert P (eds.) *Product Experience*. Elsevier, pp. 165-198.

Creswell JW and Plano Clark VL (2006) *Designing and conducting mixed methods research*. Sage, 296p.

Damala A, Cubaud P, Bationo A, Houlier P, Marchal I (2008) Bridging the gap between the digital and the physical: design and evaluation of a mobile augmented reality guide for the museum visit. Proceedings of DIMEA'08. ACM Press, pp. 120-127.

Davis FD (1989) Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3):319-339.

Demir E, Desmet P, Hekkert PPM (2009) Appraisal patterns of emotions in user-product interaction. *International Journal of Design* 3(2), 41-51.

Dennis M, Osborn L, Semans K (2009) Comparison study: early adopter attitudes and online behavior in probability and non-probability web panels. *Knowledge Networks*, Spring 2009, 1-10.

Desmet PMA (2002) Designing emotions. Doctoral dissertation, Delft University of Technology, The Netherlands.

Desmet PMA and Hekkert P (2002) The basis of product emotions. In: Green W & Jordan P (eds.) *Pleasure with Products: Beyond Usability*. Taylor & Francis: London, pp. 60-68.

Desmet PMA and Hekkert P (2007) Framework of product experience. *International Journal of Design* 1(1):57-66.

Dewey J (1925) *Experience and nature*. McCutchen Press (2008), 480p.

Dewey J (1934) *Art as experience*. Perigee book, 371p.

Dewey J (1938) *Experience and education*. Kappa Delta Pi: West Lafayette (1998).

Dey A (2001) Understanding and using context. *Personal and Ubiquituos Computing* 5(1):4-7.

Dey A, Hightower J, de Lara E, Davies N (2010) Location-based services. *Pervasive Computing* 9:11-12.

Dourish P (2001) *Where the action is: the foundations of embodied interaction*. MIT Press, 233p.

Dourish P (2006) Implications for design. Proceedings of CHI'06. ACM Press, pp. 541-550.

Dow S, Lee J, Oezbek C, MacIntyre B, Bolter JD, Gandy M (2005) Exploring spatial narratives and mixed reality experiences in oakland cemetery. Proceedings of ACE'05. ACM Press, pp. 51-60.

Drascic D and Milgram P (1996) Perceptual issues in augmented reality. Proceedings of SPIE. Vol 2653, pp. 123-134.

Dubin R (1978) *Theory building*. The Free Press, 370p.

Dünser A, Grasset R, Seichter H, Billinghurst M (2007) Applying HCI principles to AR systems design. Proceedings of MRUI'07, pp. 37-42.

Dünser A, Grasset R, Billinghurst M (2008) A survey of evaluation techniques used in augmented reality studies. Proceedings of SIGGRAPH ASIA'08, courses. ACM Press.

Ekman P, Friesen WV, Ellsworth P (1982) What emotion categories or dimensions can observers judge from facial behavior? In: Ekman P (ed.) *Emotion in the human face*. Cambridge University Press, pp. 39-55.

Falk J, Redström J, Björk S (1999) Amplifying reality. Proceedings of HUC'99. Springer, pp. 274-280.

Feiner S, MacIntyre B, Höllerer T (1997) A touring machine: prototyping 3D mobile augmented reality systems for exploring the urban environment. Proceedings of ISCW'97. IEEE, pp. 74-81.

Fishkin KP (2004) A taxonomy for and analysis of tangible interfaces. *Personal and Ubiquitous Computing* 8(5):347-358.

Forlizzi J and Ford S (2000) The building blocks of experience: an early framework for interaction designers. Proceedings of DIS'00. ACM Press, pp. 419-423.

Forlizzi J and Battarbee K (2004) Understanding experience in interactive systems. Proceedings of DIS'04. ACM Press, pp. 261-268.

Gabbard JL, Hix D, Swan II JE (1999) User-centered design and evaluation of virtual environments. *IEEE Computer Graphics and Applications* 19(6):51-59.

Gabbard JL and Hix D (2001) Researching usability design and evaluation guidelines for augmented reality (AR) systems. Available: http://www.sv.vt.edu/classes/ESM4714/Student_Proj/class00/gabbard/.

Gabbard JL, Swan II JE, Hix D (2006) The effects of text drawing styles, background textures, and natural lighting on text legibility in outdoor augmented reality. *Presence* 15(1):1-17.

Gabbard JL and Swan II JE (2008) Usability engineering for augmented reality: employing user-based studies to inform design. *IEEE Transactions on Visualization and Computer Graphics* 14(3):513-524.

Gandy M, Catrambone R, MacIntyre B, Alvarez C, Eiriksdottir E, Hilimire M, Davidson B, Collins McLaughlin A (2010) Experiences with an AR evaluation test bed: presence, performance, and physiological measurement. Proceedings of ISMAR'10. IEEE, pp. 127-136.

Gartner research and advisory company, press release (2011) Stamford, Connecticut, USA, August 10, 2011. Available: http://www.gartner.com/it/page.jsp?id=1763814. Accessed 15.2.2012.

Gartner research and advisory company, press release (2009) Sydney, Australia, November 17, 2009. Available: http://www.gartner.com/it/page.jsp?id=1229413. Accessed 22.3.2012.

Gartner research and advisory company, press release (2008) Melbourne, Australia, May 28, 2008. Available: http://www.gartner.com/it/page.jsp?id=681107. Accessed 25.1.2012.

Graeber D (2001) *Toward an anthropological theory of value: The false coin of our own dreams*. Palgrave: New York, USA.

Gremler D (2004) The critical incident technique in service research. *Journal of Service Research* 7(1):65-89.

Hansmann U, Merk L, Nicklous MS, Stober T (2003) *Pervasive computing: The mobile world*, 2nd edition. Springer-Verlag: Berlin-Heidelberg, 468p.

Hartmann J, Sutcliffe A, De Angeli A (2008) Towards a theory of user judgment of aesthetics and user interface quality. *Transactions of Computer-Human Interaction* 15(4):30p.

Hassenzahl M (2003) The thing and I: understanding the relationship between user and product. In: Blythe M, Monk AF, Overbeeke K, Wright P (eds.) *Funology: from usability to enjoyment*. Kluwer, pp. 31-42.

Hassenzahl M (2004) The interplay of beauty, goodness, and usability in interactive products. *Human-Computer Interaction* 19(4):319-349.

Hassenzahl M (2008) User experience (UX): towards an experiential perspective on product quality. Proceedings of IHM'08, vol. 339. ACM Press, pp. 11-15.

Hassenzahl M (2010) *Experience Design: Technology for All the Right Reasons*. Morgan and Claypool Publishers, 95p.

Hassenzahl M (2011) User experience and experience design. In: Soegaard M, & Dam RF (eds.) Encyclopedia of Human-Computer Interaction. The Interaction-Design.org Foundation. Available: http://www.interaction-design.org/encyclopedia/user_experience_and_experience_design.html.

Hassenzahl M and Tractinsky N (2006) User experience – a research agenda (Editorial). *Behavior & Information Technology* 25(2):91-97.

Hassenzahl M and Ullrich D (2007) To do or not to do: Differences in user experience and retrospective judgments depending on the presence or absence of instrumental goals. *Interacting with Computers* 19(4):429-437.

Hassenzahl M, Law EL-C, Hvannberg ET (2006) User experience – Towards a unified view. Proceedings of NorciCHI'06. ACM Press, pp. 1-3.

Hassenzahl M, Diefenbach S, Göritz A (2010) Needs, affect, and interactive products – Facets of user experience. *Interacting with Computers* 22(5):353-362.

Hekkert P (2006) Design aesthetics: principles of pleasure in design. *Psychology Science*, 48(2):157-172.

Hekkert P and Leder H (2008) Product aesthetics. In: Schifferstein HNJ & Hekkert P (eds.) *Product experience*. Elsevier, pp. 259-286.

Henrysson A (2007) Bringing augmented reality to mobile phones. Doctoral dissertation, Linköping university, Linköping.

Henrysson A and Ollila M (2004) UMAR – Ubiquitous mobile augmented reality. Proceedings of MUM'04, ACM Press, pp. 41-45.

Henrysson A, Ollila M, Billinghurst M (2007) Mobile phones based augmented reality. In: Haller M, Billinghurst M, Thomas B (eds.) *Emerging technologies of augmented reality: interfaces and design*. Idea Group Publishing, pp. 90-109.

Hiltunen M, Laukka M, Luomala J (2002) *Professional mobile user experience*. IT Press, Finland, 300p.

Hofstede G (2006) Dimensionalizing cultures: The Hofstede model in context. In Lonner WJ, Dinnel DL, Hayes SA, Sattler DN (eds.) *Online readings in psychology and culture, unit 2: conceptual, methodological and ethical issues in psychology and culture*. Center for Cross Cultural Research.

Holbrook MB (1996) Customer value – a framework for analysis and research. *Advances in Consumer Research*, 23:138-142.

Hsu C-L, Lu H-P, Hsu H-H (2007) Adoption of the mobile Internet: an empirical study of multimedia message service (MMS). *Omega* 35(6):715-726.

Höllerer T and Feiner S (2004) Mobile augmented reality. In: Karimi H and Hammad A (eds.) *Telegeoinformatics: location-based computing and services*. Taylor & Francis Books Ltd.

Iachello G and Abowd G (2005) Privacy and proportionality: adapting legal evaluation techniques to inform design in ubiquitous computing. Proceedings of CHI'05. ACM press, pp. 91-100.

Ishii H and Ullmer B (1997) Tangible bits: towards seamless interfaces between people, bits and atoms. Proceedings of CHI '97, ACM Press, pp. 234-241.

International Organisation for Standardisation (1998) ISO 9241-11: Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on Usability.

International Organisation for Standardisation (1999) ISO 13407: Human-centered design processes for interactive systems.

International Organisation for Standardisation (2010) ISO FDIS 9241-210: Ergonomics of human system interaction – Part 210: Human-centred design for interactive systems.

Isomursu M, Tähti M, Väinämö S, Kuutti K (2007) Experimental evaluation of five methods for collecting emotions in field settings with mobile applications. *International Journal of Human-Computer Studies* 65:404-418.

Izard CE (1977) *Human emotions*. Plenum Press, 495p.

Jackson T, Angermann F, Meier P (2011) Survey of use cases for mobile augmented reality browsers. In: Furth B (ed.) *Handbook of augmented reality*. Springer, pp. 409-431.

Jacucci G, Oulasvirta A, Salovaara A, Psik T, Wagner I (2005) Augmented reality painting and collage: evaluating tangible interaction in a field study. Proceedings of INTERACT'05, pp. 43-56.

Jonietz E (2007) MIT technology review TR10: Augmented Reality. Available: http://www.technologyreview.com/special/emerging/. Accessed 25.1.2012.

Jordan PW (2002) *Designing pleasurable products*. CRC Press, 224p.

Julier S, Baillot Y, Brown D, Rosenblum L (2000) BARS: Battlefield augmented reality system. NATO Symposium on Information Processing Techniques for Military Systems, 2000.

Juniper Research, press release (2009) Hampshire, UK, Nov 24, 2009. Available: http://juniperresearch.com/viewpressrelease.php?pr=166. Accessed 22.3.2012.

Jääskö V and Mattelmäki T (2003) Observing and probing. Proceedings of DPPI'03. ACM Press, pp. 126-131.

Kaasinen E (2005) User acceptance of mobile services - value, ease of use, trust and ease of adoption. Doctoral Dissertation, VTT Publications 566.

Kahneman D (1999) Objective happiness. In: Kahneman D, Diener E, Schwarz N (eds.) *Well-being: the foundations of hedonic quality*. Sage, pp. 3-25.

Kanade T, Narayanan PJ, Rander PW (1995) Virtualized reality: concepts and early results. Workshop on the Representation of Visual Scenes 1995, IEEE, pp. 69-76.

Kankainen A (2003) UCPCD: user-centered product concept design. Proceedings of DUX'03, ACM Press, pp. 1-13.

Kano N, Seraku N, Takahashi F, Tsuji S (1984) Attractive quality and must-be quality. *Journal of the Japanese Society for Quality Control* 14(2):39-48.

Karapanos E, Zimmerman J, Martens J-B (2009) User experience over time: an initial framework. Proceedings of CHI'09, ACM Press, pp. 729-738.

Kindberg T (2002) Implementing physical hyperlinks using ubiquitous identi¿er resolution. Proceedings of WWW'02, ACM Press, pp. 191-199.

Kleinginna PR and Kleinginna AM (1981) A categorized list of emotion definitions with suggestions for a consensual definition. *Motivation and Emotion* 5: 345-379.

Kooper R and MacIntyre B (2003) Browsing the real-world wide web: maintaining awareness of virtual information in an AR information space. *Journal of Human-Computer Interaction* 16(3):425-446.

Kruijff E, Swan E, Feiner S (2010) Perceptual issues in augmented reality revisited. Proceedings of ISMAR'10, IEEE, pp. 3-12.

Kujala S and Väänänen-Vainio-Mattila K (2009) Value of information systems and products: understanding the users' perspective and values. *Journal of Information Technology Theory & Application* 9(4):23-39.

Laugwitz B, Held T, Schrepp M (2008) Construction and evaluation of a user experience questionnaire. Proceedings of USAB'08, Holzinger A (ed.) Lecture Notes in Computer Science, vol. 5298. Springer-Verlag, pp. 63-76.

Law EL-C, Roto V, Hassenzahl M, Vermeeren A, Kort J (2009) Understanding, scoping and defining user experience: a survey approach. Proceedings of CHI'09, ACM Press, pp. 719-728.

Law EL-C and van Schaik P (2010) Modelling user experience - An agenda for research and practice. *Interacting with Computers* 22(5):313-322.

Lay EL-C (2011) The measurability and predictability of user experience. Proceedings of EICS'11, ACM Press, pp. 1-10.

Lepetit V and Berger M-O (2001) A semi-interactive and intuitive tool for outlining objects in video sequences with application to augmented and diminished reality. Proceedings of ISMAR'01, IEEE.

Lincoln YS and Guba EG (1985) *Naturalistic inquiry*. Sage, 416p.

Lindgaard G and Dudek K (2003) What is this evasive beast we call user satisfaction? *Interacting with Computers* 15(3):429-452.

Livingston M (2005) Evaluating human factors in augmented reality systems. *IEEE Computer Graphics and Applications* 25(6):6-9.

Loke S (2006) *Context-aware pervasive systems: architectures for a new breed of applications*. Auerbach Publications, 240p.

MacIntyre B, Gandy M, Dow S, Bolter JD (2004) DART: A toolkit for rapid design exploration of augmented reality experiences. Proceedings of UIST'04. ACM Press, pp. 197-206.

Mackay WE (1996) Augmenting reality: a new paradigm for interacting with computers, *La Recherche*, Mar. 1996.

Madden L (2011) *Professional augmented reality browsers for smartphones: programming for Junaio, Layar, and Wikitude*. John Wiley & Sons, Chichester, UK. 334p.

Mahlke S (2008) User experience of interaction with technical systems: theories, methods, empirical results, and their application to the development of interactive systems. Doctoral dissertation, Berlin University of Technology, Berlin.

McCarthy J and Wright P (2004) *Technology as experience*. MIT Press, 211p.

Milgram P and Kishino F (1994) A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems* E77-D(12):1321-1329.

Milgram P and Colquhoun H Jr. (1999) A taxonomy of real and virtual world display integration. *Mixed reality: merging real and virtual worlds*, Ohmsha Ltd and Springer-Verlag, pp. 5-30.

Mistry P and Maes P (2009) SixthSense: a wearable gestural interface. Proceedings of SIGGRAPH Asia'09, ACM Press, Article No. 11.

Moore GC and Benbasat I (1991) Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research* 2(3):192-222.

Morrison A, Oulasvirta A, Peltonen P, Lemmela S, Jacucci G, Reitmayr G, Näsänen J, Juustila A (2009) Like bees around the hive: a comparative study of a mobile augmented reality map. Proceedings of CHI'09, ACM Press, pp. 1889-1898.

Mullen T (2011) *Prototyping augmented reality*. John Wiley & Sons, 246p.

Myers DG (2004) Theories of emotion. *Psychology (7th ed)*, Worth Publishers, 500p.

Mäkelä A and Fulton Suri J (2001) Supporting users' creativity: design to induce pleasurable experiences. Proceedings of the Conference on Affective Human Factors, pp. 387-391.

Nagamachi M (1989) *Kansei engineering*, Kaibundo Publishing Co. Ltd.

Nielsen Norman Group (2012) Definition of user experience. Online: http://www.nngroup.com/about/userexperience.html. Accessed 1.3.2012.

Niiniluoto I (2002) *Critical scientific realism*. Oxford University Press, 355p.

Niiniluoto I (1997) *Johdatus tieteenfilosofiaan – Käsitteen- ja teorianmuodostus* (in Finnish). Otava, 314p.

Nilsson S (2010) Augmentation in the wild: user centered development and evaluation of augmented reality applications. Doctoral Dissertation, Linköping university.

Norman DA (2002) *The design of everyday things*. Basic Books, 257p.

Norman DA (2004) *Emotional design: why we love (or hate) everyday things*. Basic Books, 257p.

O'Brien HL and Toms EG (2008) What is user engagement? A Conceptual framework for defining user engagement with technology. *Journal of the American society for information science and technology* 59(6):938-955.

O'Connor PO (2008) User-generated content and travel: a case study on tripadvisor.com. In: O'connor P, Höpken W, Gretzel U (eds.) *Information and communication technologies in tourism*. Springer, pp. 47-58.

Oliver RL (1977) Effect of expectation and disconfirmation on postexposure product evaluations – an alternative interpretation. *Journal of Applied Psychology* 62(4):480.

Oliver R (1997) *Satisfaction: a behavioral perspective on the consumer*. McGraw-Hill Series in Marketing.

Olsson T, Savisalo A, Hakkarainen M, Woodward C (2012) User evaluation of mobile augmented reality in architectural planning. Proceedings of ECPPM'12. Balkema - Taylor & Francis Group, pp. 733-740.

Oppelaar ER, Hennipman E, van der Veer GC (2008) Experience design for dummies. Proceedings of ECCE'08. ACM Press, Article No. 27.

Oulasvirta A (2004) Finding meaningful uses for context-aware technologies: the humanistic research strategy. Proceedings of CHI'04, ACM Press, pp. 247-254.

Papagiannakis G, Singh G, Magnenat-Thalmann N (2008) A survey of mobile and wireless technologies for augmented reality systems. *Computer Animation and Virtual Worlds* 19(1):3-22.

Parrott WG (2001) *Emotions in Social Psychology*. Psychology Press, 378p.

Pine BJ and Gilmore JH (1998) Welcome to the experience economy. *Harvard Business Review* 110:145-172.

Pine BJ and Gilmore JH (1999) *The experience economy*. Harvard Business School Press, Boston, MA.

Platonov J, Heibel H, Meier P, Grollmann B (2006) A mobile markerless AR system for maintenance and repair. Proceedings of ISMAR'06, IEEE, pp. 105-112.

Raita E and Oulasvirta A. Too good to be bad: Favorable product expectations boost subjective usability ratings. *Interacting with Computers* 23:363-371.

Reid J, Hull R, Cater K, Fleuriot C (2005) Magic moments in situated mediascapes. Proceedings of ACE'05. ACM Press, pp. 290-293.

Rekimoto J (1996) Augmented reality using the 2D matrix code. Proceedings of WISS'96.

Remagnino P and Foresti GL (2005) Ambient intelligence: a new multidiciplinary paradigm. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans* 35(1):1-6.

Rheingold H (1991) *Virtual reality*. Summit Books, 415p.

Rifkin J (2000) *The age of access. The new culture of hypercapitalism, where all of life is paid-for experience*. Tarcher, 320p.

Rogers EM (1995) *Diffusion of innovations, 4th ed.* Free Press, 518p.

Roto V (2006) Web browsing on mobile phones – Characteristics of user experience. Doctoral dissertation, Helsinki University of Technology.

Roto V, Law EL, Vermeeren AP, Hoonhout J (eds) (2011) User experience white paper: Results from Dagstuhl seminar on demarcating user experience. Available at: http://www.allaboutux.org/files/UX-WhitePaper.pdf.

Ryan RM and Deci EL (2000) Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist* 55(1):68-78.

Sá M and Carriço L (2008) Lessons from early stages design of mobile applications. Proceedings of MobileHCI'08, ACM Press, pp. 127-136.

Satyanarayanan M (2001) Pervasive computing: vision and challenges, *IEEE Personal Communication* 8:10-17.

Schifferstein HNJ and Hekkert P (2011) Multisensory aesthetics in product design. In: Bacci F and Melcher D (eds.) *Art and the senses*. Oxford University Press, pp. 543-569.

Schmidt A (2002) Ubiquitous computing – computing in context. Doctoral Dissertation, Lancaster University.

Schnabel MA (2006) Framing mixed realities. In: Wang X and Schnabel MA (eds.) *Mixed reality in architecture, design & construction*, pp. 3-11.

Schnabel MA, Wang X, Seichter H, Kvan T (2007) From virtuality to reality and back. Proceedings of IASDR'07.

Schwartz SH and Bilsky W (1987) Toward a universal psychological structure of human values. *Journal of Personality and Social Psychology* 53:550-562.

Sheldon KM, Elliot AJ, Kim Y, Kasser T (2001) What is satisfying about satisfying events? Testing 10 candidate psychological needs. *Journal of Personality and Social Psychology* 80(2):325-339.

Silverman D (2010) *Doing qualitative research, 3rd edition*. Sage, 456p.

Sonka M, Hlavac V and Boyle R (2008). *Image Processing, Analysis, and Machine Vision*. Thomson, 800p.

Stanney K (1995) Realizing the full potential of virtual reality: Human factors issues that could stand in the way. Proceedings of VRAIS'95, IEEE, pp. 28-33.

Strauss A and Corbin J (1990) *Basics of qualitative research – Grounded theory procedures and techniques*. Sage, 272p.

Suhonen K, Väänänen-Vainio-Mattila K, Schrader M, Pölönen M, Salmimaa M, Saarikko P (2012) Two user studies on creation and evaluation of use scenarios for mixed reality communication. Proceedings of AVI'12, ACM Press.

Sutherland I (1968) A head-mounted three dimensional display. Proceedings of Fall Joint Computer Conference, pp. 757-764.

Swan II JE and Gabbard JL (2005) Survey of user-based experimentation in augmented reality. Proceedings of IEEE Virtual Reality'05, IEEE.

Swan II JE, Livingston MA, Smallman HS, Brown D, Baillot Y, Gabbard JL, Hix D (2006) A perceptual matching technique for depth judgments in optical, see-through augmented reality. Proceedings of IEEE Virtual Reality'06, IEEE, pp. 19-26.

Sward D and Macarthur G (2007) Making user experience a business strategy. In: Law E, Vermeeren APOS, Hassenzahl M, Blythe M (eds.) Proceedings of the COST294-MAUSE affiliated workshop: Towards a UX Manifesto, Landcaster, UK, 35-42.

Takatalo J, Nyman G, Laaksonen L (2008) Components of human experience in virtual environments. *Computers in Human Behavior* 24:1-15.

Teas RK (1993) Expectations, performance evaluation and consumers' perceptions of quality. *Journal of Marketing*, Oct. 1993, pp. 18-34.

Thayer RE (1989) *The biopsychology of mood and arousal*. Oxford University Press, 256p.

Thomas B, Close B, Donoghue J, Squires J, De Bondi P, Piekarski W (2002) First person indoor/outdoor augmented reality application: ARQuake. *Personal and Ubiquitous Computing* 6(1):75-86.

Tiger L (1992) *The pursuit of pleasure*. Little, Brown & Company.

Tractinsky N, Katz AS, Ikar D (2000) What is beautiful is usable. *Interacting with Computers* 13(2):127-145.

Träskbäck M (2004) User requirements and usability of mixed reality applications. Licentiate thesis, Helsinki University of Technology.

Usability Professionals' Association, UPA (2012) Usability body of knowledge glossary. Available at: http://www.usabilitybok.org/glossary. Accessed 1.3.2012.

Vaittinen T, Kärkkäinen T, Olsson T (2010) A diary study on annotating locations with mixed reality information. Proceedings of MUM'10, ACM Press, Article no. 21. doi:10.1145/1899475.1899496.

Vallino J (1998) Interactive augmented reality. Doctoral Dissertation, University of Rochester.

Venkatesh V, Morris M, Davis G, Davis F (2003) User acceptance of information technology: toward a unified view. *MIS Quarterly* 27(3):425-478.

Vermeeren AP, Law E-LC, Roto V, Obrist M, Hoonhout J, Väänänen-Vainio-Mattila K (2010) User experience evaluation methods: current state and development needs. Proceedings of NordiCHI'10, ACM Press, pp. 521-530.

Voida S, Podlaseck M, Kjeldsen R, Pinhanez C (2005) A study on the manipulation of 2D objects in a projector/camera-based augmented reality environment. Proceedings of CHI'05, ACM Press, pp. 611-620.

Von Hippel E (2005) *Democratizing innovation*. MIT Press, 204p.

Väänänen-Vainio-Mattila K, Roto V, Hassenzahl M (2008) Now let's do it in practice: user experience evaluation methods in product development. Workshop abstract in proceedings of CHI'08, ACM Press, pp. 3961-3964.

Wagner D and Schmalstieg D (2003) First steps towards handheld augmented reality. Proceedings of ISWC'03, IEEE, pp. 127-135.

Wagner D and Schmalstieg D (2009) Making augmented reality practical on mobile phones, Part 1. *IEEE Computer Graphics and Applications* 29(3):12-15.

Wagner I, Broll W, Jacucci G, Kuutti K, McCall R, Morrison A, Schmalstieg D, Terrin J-J (2009) On the role of presence in mixed reality. *Presence* 18(4):249-276.

Wang X and Dunston PS (2009) *Mixed-reality based collaborative virtual environments: specification, prototype, and evaluation in design and construction*. VDM Verlag, 107p.

Weiser M (1991) The computer for the 21st century. *Scientific American* 265(3):94-104.

Wellner P, Mackay W, Gold R (1993) Back to the real world. *Communications of the ACM* 36(7):24-26.

White S and Feiner S (2011) Dynamic, abstract representations of audio in a mobile AR conferencing system. In: Alem L and Huang T (eds.) *Recent trends of mobile collaborative augmented reality systems*. Springer, pp. 149-160.

Wiklund-Engblom A, Hassenzahl M, Bengs A, Sperring S (2009) What needs tell us about user experience. Proceedings of INTERACT'09, Part II, LNCS 5727, pp 666-669.

Wilson TD and Gilbert DT (2005) Affective forecasting: knowing what to want. *Current Directions in Psychological Science* 14(3):131-134.

Wither J and Höllerer T (2005) Pictorial depth cues for outdoor augmented reality. Proceedings of ISWC'05, IEEE, pp. 92-99.

Wither J, DiVerdi S, Höllerer T (2009) Annotation in outdoor augmented reality. *Computers & Graphics* 33(6):679-689.

Woodruff RB (1997) Customer value: the next source for competitive advantage. *Journal of the Academy of Marketing Science* 25(2):139-153.

Wright P and McCarthy J (2011) *Experience-centered design*. Morgan & Claypool, 123p.

Wright P, Wallace J, McCarthy J (2008) Aesthetics and experience-centered design. *Transactions on Computer-Human Interaction* 15(4): article 18, 21p.

Yogasara T, Popovic V, Kraal B, Camorro-Koc M (2011) General characteristics of anticipated user experience (AUX) with interactive products. Proceedings of IASDR'11, pp. 1-11.

York J and Pendharkar PC (2004) Human–computer interaction issues for mobile computing in a variable work context. *International Journal of Human-Computer Studies* 60:771-797.

Zeithaml VA (1988) Customer perceptions of price, quality, and value: a means-end model and synthesis of evidence. *Journal of marketing* 52:2-22.

Zeithaml VA, Bitner MJ, Gremler DD (2002) *Services marketing. Integrating customer focus across the firm*. McGraw-Hill, 688p.

Zhang P and von Dran GM (2000) Satisfiers and dissatisfiers: a two-factor model for website design and evaluation. *Journal of the American Society for Information Science* 51(14):1253-1268.

Original publications

Paper **I**

Olsson T, Ihamäki P, Lagerstam E, Ventä-Olkkonen L, Väänänen-Vainio-Mattila K (2009) User expectations for mobile mixed reality services: an initial user study. Proceedings of the 4th European Conference for Cognitive Ergonomics, ECCE'09, Sep 9th - Oct. 2nd 2009, Otaniemi, Espoo. ACM Press, pp. 177-184.

Paper **II**

Olsson T, Lagerstam E, Kärkkäinen T, Väänänen-Vainio-Mattila K (2011) Expected user experience of mobile augmented reality services: a user study in the context of shopping centers. Journal of Personal and Ubiquitous Computing. Springer. DOI: 10.1007/s00779-011-0494-x

Paper **III**

Olsson T, Kärkkäinen T, Lagerstam E, Ventä-Olkkonen L (2012) User evaluation of mobile augmented reality scenarios. Journal of Ambient Intelligence and Smart Environments 4(1), thematic issue on Virtual and Mixed Reality Intelligent Environments. IOS Press, pp. 29-47.

Paper **IV**

Olsson T and Salo M (2011) Online user survey on current mobile augmented reality applications. Proceedings of the 10th IEEE and ACM International Symposium on Mixed and Augmented Reality, ISMAR'11, Oct 25 – 29th, Basel, Switzerland. IEEE, pp. 75-84.

Paper **V**

Olsson T and Salo M (2012) Narratives of satisfying and unsatisfying experiences of current mobile augmented reality applications. Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems, CHI'12, May 5th – 10th, Austin, Texas, USA. ACM Press, pp. 2779-2788.

Paper **VI**

Olsson T (2012) Concepts and subjective measures for evaluating user experience of mobile AR services. Forthcoming in: Huang W, Alem L, Livingston M (eds.) Human Factors in Augmented Reality Environment. Springer, 295p. ISBN 978-1-4614-4204-2

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