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Marko Jurmu

TOWARDS ENGAGING MULTIPURPOSE PUBLIC DISPLAYS

DESIGN SPACE AND CASE STUDIES

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING,
DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

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Design space and case studies

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Abstract

This dissertation seeks to identify and discuss challenges related to the engagement process of multipurpose public displays (MPD) in urban spaces. MPD is a public display concept based on the current emergence of passive public displays, which again is part of the growth of digital signage as a medium for commercial and non-commercial content. MPDs are separated from contemporary public displays by two traits: interactivity and new use cases. Due to these traits, a better understanding of the potential of the MPD concept is needed, and this, in its turn, necessitates both a systematic and a multidisciplinary approach.

The investigation on the MPD concept and its related engagement process carried out in this thesis is divided into two phases. First, the theoretical phase is based on an extensive and analytical literature review and results in a theoretical framework based on two contributions: a layered design space for capturing the challenges related to design of MPDs in a systematic way, as well as formulation of a three-phase engagement process to model the engaging of MPDs in practice. These two formalizations facilitate reasoning on different aspects of MPD design, and thus scaffold future designs and deployments. Second, the empirical phase is based on a collection of case studies each of which investigates selected sections of the overall theoretical framework along with serving to illustrate how the sections under investigation operationalize in practice. The overall contribution of this dissertation is thus both to lay out a framework for a wider research area, as well as to raise selected findings as part of the framework through the case studies.

The findings derived on the basis of the design space, as well as the engagement process indicate the complexity of the design process for MPDs, even in cases where only the aspects of human-computer interaction (HCI) are considered. They also serve to raise the importance of non-functional issues in real-world MPD deployments, most notably, the mental models embodied by current public displays that citizens implicitly transfer over to MPDs as well. For future designs, careful leveraging of existing practices and mental models is crucial to facilitate the adoption of MPDs and to fully realize their potential as flexible urban computing tools.

Keywords: human-computer interaction, interactive public displays, ubiquitous computing, urban computing

Jurmu, Marko, Kohti monikäyttöisiä julkisia näyttöjä kaupunkitiloissa. Suunnitteluavaruus sekä tapaustutkimuksia
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Tiivistelmä

Tämä väitöskirja pyrkii tunnistamaan ja analysoimaan monikäyttöisten julkisten näyttöjen (multipurpose public display, MPD) käyttöön liittyviä haasteita. MPD on uusi kaupunkitiloissa olevien julkisten näyttöjen konsepti, joka perustuu nykyisten passiivisten julkisten näyttöjen sekä niissä esitettävän digitaalisen kyltityksen (digital signage) pohjalle. MPD eroaa konseptitasolla nykyisistä julkisista näytöistä pääasiassa kahdella tavalla: interaktiivisuudella sekä uusilla käyttötarkoituksilla. Näistä eroavaisuuksista sekä kaupunkitilojen yleisemmästä luonteesta johtuen MPD-konseptin parempi ymmärrys ja sitä kautta hyödyntäminen tulevaisuudessa edellyttää sekä järjestelmällistä että tieteidenvälistä tutkimusotetta.

Tässä työssä tehty tutkimus jakaantuu ylimmällä tasollaan kahteen vaiheeseen. Ensimmäinen teoreettinen vaihe pohjautuu laajaan kirjallisuuskatsaukseen ja kulminoituu teoreettiseen viitekehykseen, joka koostuu kahdesta osasta. Ensimmäinen osa on kerroksittainen suunnitteluavaruus (design space), jossa pyritään MPD-konseptiin liittyvien haasteiden ja mahdollisuuksien kartoittamiseen tutkimuksen nykytila huomioonottaen. Toinen osa on teorisoitu esitys MPD-konseptin käyttöprosessista (engagement process) kaupunkilaisten näkökulmasta koostuen kolmesta osittain limittyvästä vaiheesta. Nämä kaksi teoreettista osaa tarjoavat pohjaa MDP-konseptiin pohjautuvalle suunnittelulle tulevaisuudessa. Toinen empiirinen vaihe rakentuu kolmen tapaustutkimuksen kokoelmasta, jossa jokainen yksittäinen tapaustutkimus pohjautuu tiettyihin esitetyn teorian osa-alueisiin ja näin ollen myös esittelee, miten suunnitteluavaruus sekä käyttöprosessin malli voivat realisoitua käytännössä. Työn kontribuutio koostuu siis laajemman teoreettisen kehyksen muodostamisesta sekä tämän kehyksen määrittämässä fokuksessa tehdyistä tapaustutkimuksista.

Työssä saavutetut tulokset auttavat hahmottamaan MPD-konseptiin liittyvän suunnittelun kompleksisuutta tilanteissa, joissa on keskitytty pääasiassa ihminen-kone vuorovaikutuksen (human-computer interaction, HCI) tutkimiseen. Tapaustukimukset nostavat esille myös ns. non-funktionaalisten tekijöiden roolin autenttisissa kaupunkitiloissa tapahtuvassa empiirisessä ja konstruktiivisessa tutkimuksessa. Tässä tärkeään rooliin nousevat etenkin niin kutsutut mentaalimallit, joiden kautta kaupunkilaiset hahmottavat MPD-konseptia. Työn tulosten perusteella voidaan todeta, että MPD-konseptiin pohjautuvassa suunnittelussa tulee korostaa olemassa olevien urbaanien sosiokulttuuristen käytäntöjen roolia. Näin MPD-konseptin käytöstä voidaan tulevaisuudessa saada sujuvampaa ja luontevampaa, ja MPD-konsepti voisi tulevaisuudessa olla keskeisempi osa urbaania sosiokulttuurista rakennetta.

Asiasanat: ihminen-kone vuorovaikutus, interaktiiviset julkiset näytöt, jokapaikan tietotekniikka, urbaani tietotekniikka

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Oulu, October 2014 Marko Jurmu

List of original articles

The original articles used in this compound dissertation are listed below. Each article was published in English in an international conference proceeding, including a peer-review practice; all are printed in this dissertation in their entirety. The articles are listed below in the order in which they were published.

I Jurmu M, Boring S & Riekki J (2008) ScreenSpot: Multidimensional resource discovery for distributed applications in smart spaces. Proc. Fifth Annual International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (MobiQuitous'08), Trinity College Dublin, Ireland: Article No. 41. DOI: 10.4108/ICST.MOBIQUITOUS2008.3576.

II Boring S, Jurmu M & Butz A (2009) Scroll, tilt or move it: Using mobile phones to continuously control pointers on large public displays. Proc. 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7 (OzCHI'09), Melbourne, Australia: 161-168. DOI: 10.1145/1738826.1738853.

III Hosio S, Jurmu M, Kukka H, Riekki J & Ojala T (2010) Supporting distributed private and public user interfaces in urban environments. Proc. Eleventh Workshop on Mobile Computing Systems and Applications (HotMobile'10), Annapolis, MD, USA: 25-30. DOI: 10.1145/1734583.1734590.

IV Jurmu M, Kukka H, Hosio S, Riekki J & Tarkoma S (2011) Leasing service for networks of interactive public displays in urban spaces. Proc. Sixth International Conference on Advances in Grid and Pervasive Computing (GPC'11), Oulu, Finland: 198-208. DOI: 10.1007/978-3-642-20754-9_21.

V Jurmu M, Ogawa M, Boring S, Riekki J & Tokuda H (2013) Waving to a touch interface: Descriptive field study of a multipurpose multimodal public display. Proc. Second ACM International Symposium on Pervasive Displays, Mountain View, CA, USA: 7-12. DOI: 10.1145/2491568.2491571.

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1 Introduction

1.1 Motivation

The relationship between humans and computers has significantly changed in the past three decades. While during the introduction of the PC in the 1970s and 80s, we *used* computers, in the 2010s, we *live* with them (Sellen *et al.*, 2009). Larger underlying trends such as digitization and miniaturization of electronics have enabled major sociotechnical transformations that have radically changed how we perceive computers and computation, and more specifically, what constitutes a user interface. This rapid development has raised many societal tensions and led the human-computer interaction (HCI) (Dix *et al.*, 2004) community to critically re-examine the mainstream methodologies in designing interactive technologies within this new relationship. Interaction design (Rogers *et al.*, 2011), a recent sub-field of HCI, was motivated largely by the infusion of digital information processing to processes and artefacts previously thought as analogue and mechanical (Cooper, 2004). In other words, technology is moving out to the real world at a fast pace, and without a comprehensive understanding of the related phenomena, as well as of the core methodologies, we risk underutilizing this ongoing major technological shift.

One of the most profoundly affected venues in this transformation is the modern city. Cities in the developed world experience a continuous influx of both people and technology. The influx of people to cities is motivated by perceived improvements in education, employment and living conditions. In 2012, 52.6% of the world's population was living in cities (The World Bank, 2014), with a rising trend predicting 75% urbanization for the year 2050 (OECD, 2012). In this dissertation, individuals living in cities will be referred to as 'citizens', while other options such as 'city dweller' or 'urbanite' would also suffice. The influx of technologies on the other hand is a result of *ubiquitous computing*, also referred to as the third wave of computing, which complements mainframes and personal computers through embedding of sensing, computation and actuation in physical living environments (Abowd & Mynatt, 2000). Taken together, these trends indicate that contemporary and future urban spaces are increasingly entangled with heterogeneous technological infrastructures, and that communities as well as individual citizens will increasingly enact everyday cultural practice in urban spaces through utilization of these infrastructures (Williams & Dourish, 2006). As

Brynskov *et al.* (2014) state, *"urban public space is both shaped by and shaping the digital technologies, media and materials that are becoming increasingly formative to communities"*. Tangible examples of this transformation are the gradual disappearance of public phone booths and paper-based maps in urban spaces as people access rich, personalized and context-aware communication and navigation services on their personal mobile devices through wireless digital access networks such as 3G, LTE and public Wi-Fi. This reliance on digital services, and especially on social media, is irrevocably changing the legibility of cities, and thus impacts the way citizens negotiate urban spaces in everyday contexts (Dourish, 2006a).

The influx of technology to cities, its role in the cities, and the meaningful ways for people to utilize this heterogeneous mesh of resources have gained an interest in academic communities within the last decade, leading to new research areas such as *urban computing*, *urban informatics* and *urban interaction design*. In this dissertation, I will exclusively use the term urban computing to encompass all of these emerging research areas. Urban computing concerns itself with the integration of computing, sensing and actuation technologies into everyday urban settings and lifestyles, as well as with the HCI aspects resulting from this integration (Kindberg *et al.*, 2007). Since urban computing focuses on the intersection of people, space and technology in an urban context, it necessitates a multidisciplinary theoretical framework that acknowledges not only technological but also architectural and sociocultural aspects of urban spaces (Foth *et al.*, 2011). This intersection also means that the methodology of urban computing necessitates real-world contexts, and that prototypes of new technologies cannot be fully evaluated exclusively in laboratory environments. For this reason, a new evaluation paradigm called *in-the-wild* evaluation is emerging (Johnson *et al.*, 2012). It emphasizes real-world contexts in evaluation, and at the same time acknowledges the lessened control over technology use from the researchers' side. Theoretical and epistemological foundations of in-the-wild evaluation are currently an active research topic within the urban computing area (Rogers, 2011).

This dissertation discusses *multipurpose public displays* (MPD) (Ojala *et al.*, 2012) as an exemplary technological artefact of urban computing, and more specifically, how citizens come to meaningfully utilize this novel public technology. Whereas passive digital public displays have a history of several decades in broadcasting of digital signage in public urban spaces, MPDs differ from these displays in two important aspects. First, they are interactive, which means that citizens can engage the displays beyond a mere viewing experience and the content can be designed to leverage interaction. Second, MPDs support application areas beyond digital signage, and are emerging as a diverse tool for various urban computing use cases such as civic engagement (Hosio *et al.*, 2012; Schroeter *et al.*, 2012), gaming and gamification (Ballagas *et al.*, 2007; Müller *et al.*, 2012), new media (Tuulos *et al.*, 2007) and interpersonal communication for example in forms of communicative ecologies and social triangulation (José *et al.*, 2008; Memarovic *et al.*, 2012). This dissertation exclusively discusses MPDs as interactive public display technology.

These two traits, interactivity and new application areas, establish MPDs as a distinctive class of computational resources for urban computing. This distinction from conventional public displays requires new approaches for designing interactive and context-aware content, and in broader terms, spans a new *design space* into the research area of urban computing. This new design space has received attention form researchers within the last years (Müller *et al.*, 2010), and also forms the high-level focus of this dissertation. MPDs at the moment are by their very nature both foreign and novel to citizens. This means that prior user experience cannot be assumed, and that citizens may not have clear *mental models* regarding the purpose and functionality of this new artefact. Finally, the entire interaction setting is situated within a public urban space, making it an inherently social process. This evokes the metaphor of *a stage*, framing interactions with MPDs as social 'acting' for a dynamically changing audience (Kuikkaniemi *et al.*, 2011).

This dissertation denotes as *engagement process* the collection of pragmatic strategies and ways in which the utilization of MPDs by citizens manifests itself in practice. An important part of understanding this manifestation is in uncovering how different aspects of the design space impact the engagement process. Both the engagement as a term and the related process are explained in detail in Chapter 2. Previous approaches have adopted a step-wise model (Brignull & Rogers, 2003; Müller *et al.*, 2010; Vogel & Balakrishnan, 2004), and this dissertation presents a model that divides this process into three steps, each shortly introduced below.

First, citizens need to *discover* the interactive public display from the more general urban visual scenery, and especially, the interactivity itself. It is still more common to encounter passive public displays than interactive ones, so the interactivity needs to stand out as a feature and be clearly communicated (Kukka *et al.*, 2013). Failures to discover the display artefact and the associated interactivity are referred to in the literature as *display blindness* (Huang *et al.*, 2008) and *interaction blindness* (Ojala *et al.*, 2012), respectively. Both phenomena are complex in nature and comprise of several factors regarding the display artefact, the surrounding space and the audience.

The second step is the *sense-making* process, during which the citizens might formulate questions related to the artefact such as “what is this”, “how do I use it” and “is this useful for me in my current context”. An important part of the sense-making is to find a *mental model* (Müller *et al.*, 2010) with which the artefact can be meaningfully associated. Otherwise, the sense-making process can fall short and the actual interaction may not take place. Due to prevalence of digital color-TV sets at homes as well as passive digital signage displays on urban places, citizens sometimes refer to public displays as “public TVs” (McCarthy *et al.*, 2009). Although so-called ‘smart TVs’ are currently emerging in domestic environments, this mental model is restricting, as the term TV conceptually evokes images of a passive viewing experience, and this again frames the expectations citizens will have towards the artefact. Thus, it becomes a research challenge to actively communicate meaningful mental models regarding MPDs, and especially to scaffold the forming of potentially new mental models for MPDs through design.

The third step of the engagement process is the actual *interaction* with the MPD. What makes the interaction phase complex is that citizens are in no way mandated to interact with MDPs only in ways originally modeled in the design space. This means that new interaction mechanisms and styles can be invented by citizens on-the-fly, such as re-formulating a photo-browsing canvas into an approximation of a football game (Peltonen *et al.*, 2008). The concept of *non-interaction* is also a recognized phenomenon, and occurs when citizens perceive the interactive affordance of the display but consciously choose not to interact with it (O’Hara, 2010). Additionally, the ways that groups of people interact with a public display can be very dynamic, not necessarily following the rules approximated in the design space, as was evidenced for example by Marshall *et al.* (2011) in their field trial on tabletops in tourist offices. Interaction phase should not be seen clearly separated from the sense-making phase, and the two often complement each other in a reciprocal fashion. This speaks of the challenges in codifying aspects related to the interaction within the design space.

The short introduction above illustrates the fact that interactive public displays in urban spaces have potential for providing engaging functionalities that would be genuinely formative to urban sociocultural practice. Based on this potential, this dissertation sets its sight to a further vision: one where MPDs act as multipurpose tools for urban computing, and where citizens engage MPDs as parts of everyday sociocultural practices. This type of adoption, coupled with a significant increase of volume in urban public displays, leads to a situation where current models of engagement based on emergent interactions become potentially insufficient and require additional functionality to balance usage. Based on the current state of research into interactive public displays, this dissertation proposes additional functionalities for the engagement of MPDs in urban contexts based on issues arising from increased adoption and scale.

1.2 Objectives and methodology

In its broadest focus, this dissertation investigates the following research question:

How can multipurpose public displays facilitate the engagement process in order to establish MPDs as an everyday artefact of smart urban spaces?

Inherent to this question formulation is the active role of the display artefact itself: a design space for MPDs needs to embody mechanisms where the display actively communicates its interactive as well as functional capabilities to citizens, in order to facilitate engagement. Especially interesting in this research setting is in-the-wild testing, meaning longitudinal evaluations in real-world urban spaces without researcher supervision (Johnson *et al.*, 2012; Rogers, 2011). As also evidenced by Ojala *et al.* (2012), longitudinal evaluations in ecologically valid contexts bring out so-called *emergent behavior* between the system and the citizens engaging it, and highlights the inevitable effects of several non-functional aspects such as weather (Ylipulli *et al.*, 2014) and maintenance (Heikkinen *et al.*, 2010). The importance of in-the-wild testing has recently been voiced within the HCI community (Greenberg & Buxton, 2008; Ojala *et al.*, 2012; Rogers, 2011; Rogers *et al.*, 2007) as part of a larger paradigm shift in how computer systems should be designed, deployed and evaluated in the future.

This dissertation proposes a labeling of two distinctive usage models of an MPD as *opportunistic* and *deterministic*. Whereas opportunistic use can be characterized as ‘stumbling upon’ a display artefact and shortly interacting with it, deterministic use is described through more clear, a priori articulated goals with regards to interactions with the display. Ultimately, the discriminating factor between these usage models is *motivation*. Motivation for opportunistic use emerges on-the-fly through external stimuli, and is mostly built on the elements of curiosity and playfulness. Deterministic use is motivated a priori by linking the utilization of an MPD to a task or a set of tasks that the citizen has at a specific moment, and this type of motivation gives rise to new functionality related to the engagement process. Especially, it gives rise to mental models of MPDs that go beyond passive viewing and ephemeral interactions.

To pay special emphasis/attention to deterministic use, and to facilitate the adoption of the deterministic usage model as part of MPDs, this dissertation complements the proposed engagement process with the notions of *mapping* and *arbitration*. Mapping extends existing opportunistic and in-situ models of discovering public displays with an actual service discovery protocol, and thus goes beyond the social conventions of polling, queuing and exploring. Within mapping, a central requirement is that the public displays supporting mapping are internetworked to form a functional whole that citizens can query through suitable client software residing within their personal smartphones.

Arbitration on the other hand is the process of identifying and resolving access conflicts, which can arise from contending access attempts. In order for MPDs to arbitrate access, a formal notion of ownership needs to be defined. Within the case studies of this dissertation, the notion of a *context-aware lease* is proposed as a formal way of arbitrating, i.e. scheduling, access to a single MPD. Following this definition, the procedures of how an MPD accepts incoming leases as well as manages existing leases forms a basis for how this dissertation sees the utilization of MPDs to take form in future urban spaces.

Mapping and arbitration are thus services that each MPD in an internetworked whole offers for citizens who are deterministically utilizing MPDs for a given sociocultural practice. The earlier statement of MPDs actively communicating both interactive and functional affordance to citizens is realized in mapping and arbitration when citizens first query the network of MPDs through mapping, followed by setting a lease to a target MPD and based on the arbitration functionality of the target MPD, eventually engage and interact with it. In comparison, the questions of availability and conflicting access are less meaningful issues in opportunistic interactions. However, the author's argument in this dissertation is that systems designed for opportunistic use have a limited room for scaling up when the engagement of interactive public displays becomes an everyday urban activity, their utilization in terms of use cases gets varied, and the motivation driving the use emerges from task-related needs as opposed to emergent curiosity.

Based on the argumentation on mapping and arbitration, the original high-level research question of this dissertation can be broken down into two objectives as follows:

The first objective is to extend the current design space of interactive multipurpose public displays with the proposed three-phase engagement process as well as with the functionalities of mapping and arbitration.

The second objective is to constructively investigate how the three phases of the proposed engagement model are affected by the functionalities of mapping and arbitration.

These two objectives form the core of this dissertation. The first objective refers to theoretical work, where based on a comprehensive literature review, the current state of the art within interactive public displays will be drawn together as a design space. This design space acts both as an operationalization for other researchers in that it provides guidelines for design and deployment, and acts as an analytical basis for the constructive and empirical case studies presented in Chapter 3. The case studies serve to illustrate parts of the design space, and thus act as examples on how the design space operationalizes in practice. The two objectives also set the methodology of this dissertation within two parts, where the background and construction of the design space follows a theoretical research approach, while the case studies adhere to a constructive and empirical method. Furthermore, the case studies also present a combination of evaluation approaches for interactive public displays: user testing in a laboratory, semi-controlled field trial, as well as an in-the-wild evaluation without active researcher participation.

1.3 Scope

MPDs are urban computing artefacts through which several different *stakeholders* of the urban space come together. Examples are the city administration, advertisers, application developers, location managers of deployment locations, researchers, and finally, citizens as individuals as well as in various communities. For the purpose of keeping the scope of this dissertation within aspects of HCI and the user experience arising from interactions with MPDs, the author intentionally limits the scope to deal purely with the MPD as an artefact, and the citizens as a stakeholder. This means that issues dealing with value chains and general valuation of MPDs, as well as the CAPEX and OPEX[1] related to MPD deployments are left out of the scope.

This dissertation also refrains from discussing any specific application area of MPDs in depth. As the focus is within the interaction and the user experience *per se*, focusing on a single application area would draw the specifics of that application area into focus, whereas in this dissertation, the MPD itself as a concept and a physical artefact within the urban space comprises the main focus. At the same time, this dissertation fully acknowledges that research into existing and potential application areas of MPDs is crucial in driving the overall adoption of MPDs into urban sociocultural practices.

Finally, this dissertation focuses only on public displays that feature two traits: first, they are digital and thus based on a matrix of dynamic pixels whose contents can be changed within a certain refresh rate supported by the associated display technology. Second, they are controlled by a dedicated computer unit that is connected to the Internet, meaning that both the acquisition of status information from the display, as well as delivery of control and content data can be handled through the Internet. This limiting intentionally leaves out of focus any public display concepts not based on pixel matrices, such as street art-based public displays (Koeman *et al.*, 2014). Additionally, public displays without Internet connectivity, presenting locally stored content, are excluded. This limiting serves to further highlight the vision embodied by this dissertation, where interconnected and Internet-enabled MPDs present designers, researchers and citizens with a flexible tool in supporting urban sociocultural practices.

1.4 Contributions

Contributions of this dissertation are as follows:

- A three-phase engagement process related to interactive public displays, as well as definition of two additional functionalities to this engagement process, namely mapping and arbitration.

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[1] CAPEX refers to *capital expenditure* related to an acquisition, while OPEX refers to *operational expenditure* related to the acquired investment.

Through this engagement process, this dissertation also highlights the deterministic usage model as a complementary way for engaging MPDs.

- A layered and hierarchical design space based on a literature review. This design space provides guidelines on how different aspects of public displays operationalize in practice.
- Three case studies that provide empirical insights into parts of the presented design space, as well as highlight different methodologies that public display research currently embodies.
- Discussion of empirical data from a real-world infrastructure of seventeen multipurpose public displays (UBI-hotspots) installed in an authentic downtown setting of Oulu, Finland.

Below, the contributions of each individual publication are discussed in relation to the contribution list given above. Figure 1 illustrates how these publications situate within the overall focus area of this dissertation.

Publication I (PI) presents a design and implementation of mapping software implemented as a mobile client for a personal smartphone, coupled with associated middleware facilities on each MPD. Through this client, a citizen can query the entire network of MPDs as one whole, and through the associated visualization, gain an aggregated overview of locations and availabilities of MPDs. The prototype system's design and implementation for PI was carried out jointly between the principal author and the co-author of the publication, Sebastian Boring, then affiliated with the Ludwig-Maximilians University (LMU) in Munich, Germany. The principal author and the co-author also carried out a small-scale lab-based evaluation for the prototype with simulated availability information to verify the designed functionality.

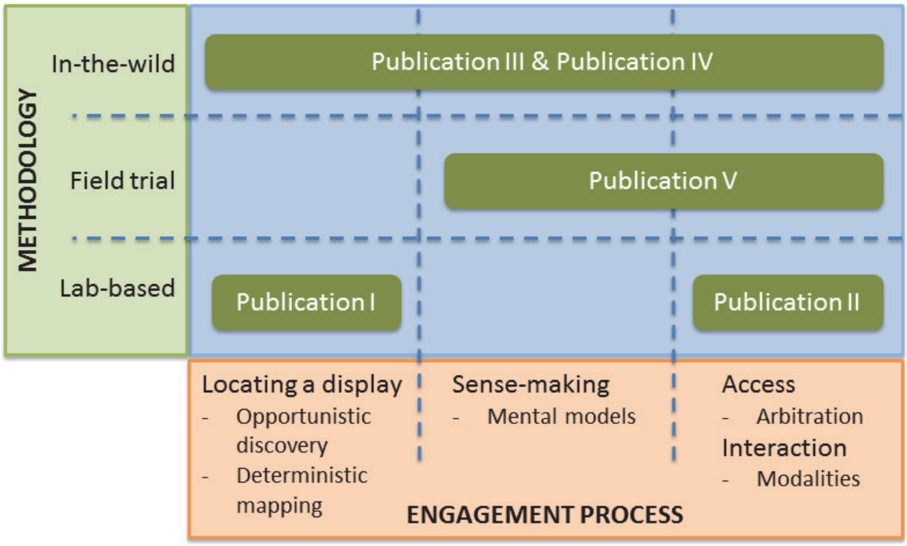

Fig. 1. Focus areas of individual publications within this compound dissertation.

Publication II (PII) was another co-operation between the author and Sebastian Boring, and was published based on joint work carried out at LMU while the author was a visiting researcher there. It focuses on the interaction phase of the engagement process in laboratory conditions, and provides design guidelines for distributed applications which feature mobile input and an interactive public display as an output device. Furthermore, the focus was on evaluating the feasibility of different mobile input techniques for controlling personal cursors on a shared public display canvas. This publication does not directly discuss issues related to mapping and arbitration, but instead looks at the main research question from the viewpoint of the interaction phase. Although the author is a second author in the publication, his role was active throughout the research and the subsequent writing and reporting process.

Publications III and IV (PIII, PIV) are based on a longitudinal in-the-wild evaluation of a context-aware leasing prototype that covers all phases of the engagement process while focusing especially on the system-level performance and citizen-based assessment of an arbitration service that leverages the leasing functionality. The lease-based arbitration was designed and implemented through an RFID tag accessory attached to a smartphone, and an RFID reader unit on each MPD. The arbitration itself was designed to differentiate between exclusive and social use, and to manage the requested leases as a straightforward FIFO queue. The prototype was designed and implemented at the University of Oulu between the author and his colleague Dr. Simo Hosio, so that the author was responsible for the MPD side, while Dr. Hosio was responsible for the smartphone side. Consequently, the focus areas in the publications are divided so that while PIII pays more focus to the mobile client and the example applications implemented on top of the leasing functionality, PIV focuses on the middleware aspects of the leasing functionality on the side of the MPD, as well as reporting on citizen assessment through interview data. The prototype utilized the UBI[2] infrastructure of MPDs, located in Oulu, Finland.

Publication V (PV) is an MPD prototype called FluiD, which utilizes the combination of a multi-touch display and a Microsoft Kinect controller. Based on the Kinect controller, a set of interactions based on the theory of proxemics were designed and implemented for the purpose of engaging the public display. These interactions included the presence and orientation within the front area of the display, as well as a set of mid-air gestures that could be performed when residing in front of the display and being oriented towards it. Two example applications were designed so that they required users to switch away from mid-air gesturing to another interaction modality. The first one, an example of a localized advert, encouraged users to capture a QR-code with a smartphone, while the second one, a map service, utilized the multi-touch panel for interaction. The FluiD prototype was designed, implemented and evaluated by the author and Ph.D. student Masaki Ogawa at Keio University in Tokyo, Japan, where the author spent one year as a visiting researcher. Consequently, the associated publication is also written by the author, while Mr. Ogawa and Professor Hideyuki Tokuda acted as co-authors.

1.5 Structure

This dissertation is structured as follows: Chapter 2 provides a critical review of theoretical and methodological underpinnings of ubiquitous computing, urban computing and interactive public displays, as well as illustrates how HCI methodologies have evolved. Based on this review, a layered model of a design space for public displays in urban spaces is presented, where the reviewed work comes together and the layered structure illustrates how different aspects impact

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[2] http://www.ubioulu.fi/en/

the overall design. Chapter 3 presents a collection of case studies that empirically and constructively investigate parts of the design space, and also act as examples of how the design space operationalizes in practice. Chapter 4 discusses the objectives and contributions of this dissertation in detail, and Chapter 5 concludes the dissertation with an outlook on the future of this research area.

2 Background and theory

Societies and cultures are in a constant reciprocal relationship with tools and technologies: society molds tools and technologies, and conversely, the usage of tools and technologies molds society. Through this reciprocity, certain technologies become inherent parts of society and its sociocultural practice. A key part of this relationship is the gradual adoption of new technologies. This chapter lays out the core terminology, as well as the theoretical concepts and processes relevant to this dissertation in terms of new technologies emerging to public urban spaces, ending with a design space for MPDs as an urban computing artefact. Through the discussion of a larger theoretical and epistemological framework, this chapter creates a backdrop for both the design space, as well as the case studies.

2.1 Ubiquitous computing

> *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*
> *- Mark Weiser*

Ubiquitous computing (ubicomp) is generally recognized as the third major paradigm of computing. After the invention of the transistor as a core element of computer processors in the late 1940s, computing first took the form of *mainframe* computers that were physically large machines shared by multiple people who had intimate knowledge of the machines' inner workings in order to program it. In 1971 and 1972, Intel ushered in the era of microprocessors with the introduction of 4004 and 8008 models, respectively. They and subsequent models eventually led to the introduction of the *personal computer (PC)*, which caused two major transformations. First, PCs were intended for personal use, which opened their potential for office and later also domestic scenarios. Second, the programming interfaces of PCs were on a higher level of abstraction, allowing larger demographics to access the programmable features and thus enabling individuals to innovate by using the PC as a platform.

In 1991 when PCs were still the mainstream paradigm of computing, Mark Weiser, then working at Xerox PARC, introduced in a research publication a vision for the third paradigm of computing that he termed as *ubiquitous* *computing* (Weiser, 1991). He and PARC colleagues approximated the trends of continuing physical miniaturization of computers to envision scenarios where humans are in their everyday environments surrounded by a multitude of computational devices that seamlessly blend into these environments. A major sociotechnical change in ubiquitous computing compared to PCs comes from interaction between humans and this blended technology, which is envisioned as embodying implicit and context-aware traits. This frames interactions with ubiquitous technologies similar to those with a personal butler, something that one can draw attention to when necessary, and which afterwards disappears to the periphery of attention. This new mode of interaction was referred to by Weiser as *calm computing* (Weiser & Brown, 1997).

After its inception, the vision of ubiquitous computing has received significant attention from academia. Abowd and Mynatt (2000) reviewed the underpinnings of ubiquitous computing and suggested that everyday activities and practices be placed to the center of ubiquitous computing research agenda. This opens up new challenges within social implications of ubiquitous computing in terms of varied interaction methods with novel technologies in open-ended tasks, as well as in how ubicomp systems should be evaluated. Instead of silver bullets in technology evaluation, different methods should be seen as forming a spectrum 'from technology feasibility efforts to long-term use studies – but a user-centric perspective is always possible and necessary' (Abowd & Mynatt, 2000). Bell and Dourish (2007) criticized the focusing on forthcoming technological 'proximal futures' within ubiquitous computing, and assert that emphasis should instead be put on multidisciplinary understanding of how existing and upcoming technologies can support 'the inherent messiness of everyday life'.

Examining the recent critical treatises on ubiquitous computing, there is now a tendency to see Weiser's original vision from two complementary viewpoints: one is a technological agenda where *technology enablers*, i.e. different computational building blocks, are moving into place and thus laying the bedrock for the overall vision. The other is a more philosophical agenda that calls for significant qualitative changes in everyday *lived experiences* that are formative of these technological enablers, that is, ubiquitous technologies play a significant role in structuring the experience. Ferscha (2012) investigated the technology enabler side of the vision in an extrapolative fashion by situating contemporary technologies to the vision, and laying out future steps of engineering challenges accordingly. Abowd (2012), on the other hand, recently highlighted an intellectual crisis on the technological side of ubiquitous computing research by claiming that the technology enablers are now spread throughout computing in general, and thus maintaining a separate identity for ubiquitous computing is becoming meaningless.

Considering the change in lived experiences, Rogers (2006) expressed criticism on the principle of calmness as inviting an unnecessarily sedated lifestyle, and instead calls for ‘engaging ubicomp experiences’, i.e. interactions with ubiquitous technology that physically engage the human in relation to the real-world surroundings. This standpoint clearly juxtaposes with the original vision regarding how lived experiences should be supported by technological enablers, suggesting that the experience should instead be formative of physical exertion and engagement with both technology and the physical surroundings. This type of formation of lived experiences can be seen as a philosophical basis in contemporary prototypes that support for example physical exercise (Consolvo *et al.*, 2008) or playful experiences (Chatham & Mueller, 2013).

Jeffrey and Shaowen Bardzell (2014) suggested that the lived experiences side of ubiquitous computing’s original vision has become more or less obsolete, and that to reinvigorate it, designers and researchers should engage in so-called *cognitive speculation* that is part of science-fiction theory and

“is characterized as speculative thinking that is grounded on the most current science (social, computer, and physical) and enhanced with imaginative extrapolation that is informed and shaped by a systematic and intellectually rigorous interpretation of comparable moments in the past”.

A similar recommendation has also been given by Dourish and Bell (2013) in a recent article. Based on these viewpoints, it can observed that the lived experiences side of the vision always drives the technological enablers, and if these enablers are commonly accepted as reached, the field of ubiquitous computing in general arrives to a meaningless position. This position remains stagnant until the lived experiences side is updated and reinvigorated through cognitive speculation that builds informed future scenarios formative of current technological enablers, and this new iteration again drives technology and engineering research in order to realize these enablers. We can thus conclude that ubiquitous computing is an iterative reciprocal effort between informed visions of future and how technologies should be developed based on these informed visions, and that technology development without this informed vision is less meaningful.

2.2 Urban computing

In this section, three emerging research areas are presented that are all concerned on the subject of how public urban spaces and sociocultural practices therein should be formative of ubiquitous computing technologies. These areas are called *urban computing*, *urban informatics* and *urban interaction design*. For the sake of simplicity and non-exhaustive argumentation, these are each shortly presented and analyzed, after which key features from each are conjoined within the focus of this dissertation, and finally, this conjoining is commonly referred to as *urban computing* for the remainder of this dissertation. The differences in labelling stem from relative emphases within a common multidisciplinary focus, and since this dissertation originates from a computer science background, it is apt that the label 'urban computing' is used as a common denominator.

The definition for urban computing comes from previously discussed foundations of ubiquitous computing when applied to a certain types of locations that jointly make up what is known as the *public urban space*. Although urban areas also contain spaces not public, urban computing has taken as its focus the interactions between ubicomp and citizens in public urban spaces. Kindberg *et al.* (2007) have coined the following computer science-driven definition for urban computing:

"Urban computing [is] the integration of computing, sensing, and actuation technologies into everyday urban settings and lifestyles."

What makes this a very engineering-driven definition is that the sociocultural status quo has been reduced to notions of 'settings' and 'lifestyles', and the sociotechnical process of how these technologies come to be essential building blocks of urban computing is reduced to 'integration'. The definition implicitly assumes that ubiquitous computing technologies will improve these aforementioned settings and lifestyles, and that in a deterministic fashion, technology can and will have a role to play in them. This definition can be considered as the most broad and technology-oriented of the definitions covered in this chapter.

Urban informatics research area emerged from a series of workshops called *Digital Cities*, after which Marcus Foth, Laura Forlano, Christine Satchell and Martin Gibbs proceeded to edit a book on the subject, titled 'From Social Butterfly to Engaged Citizen: Urban Informatics, Social Media, Ubiquitous

Computing, and Mobile Technology to Support Citizen Engagement' (Foth *et al.*, 2011). The introduction of the edited work states that *"this book is about engagement with communities, cities, and spaces through the use of digital tools, applications, and devices"*, but makes distinctions to rudimentary visions of ubiquitous computing and thus urban computing by stating that *"theoretically, urban informatics research has moved beyond simplistic proclamations of 'anytime, anywhere' access to data, information, and networks toward the integration of technologies into meaningful cultural practices contextualized in specific communities, cities and spaces"*. In methodological sense, *"there is a need for experimentation with new combinations of methods in order to capture and analyze data from people, technologies, and environments"*.

Similarly to the definition of urban computing, the integration of technologies is in the focus of urban informatics, but now the communities of citizens are also being brought into focus. As illustrated in Figure 2 (Foth *et al.*, 2011), urban informatics places itself in the center of three overlapping focus areas: *people*, *place* and *technology*. Methodological challenges arise from both sociocultural as well as architectural differences within cities, and this means that technology must properly adapt to the different unique combinations of people and places.

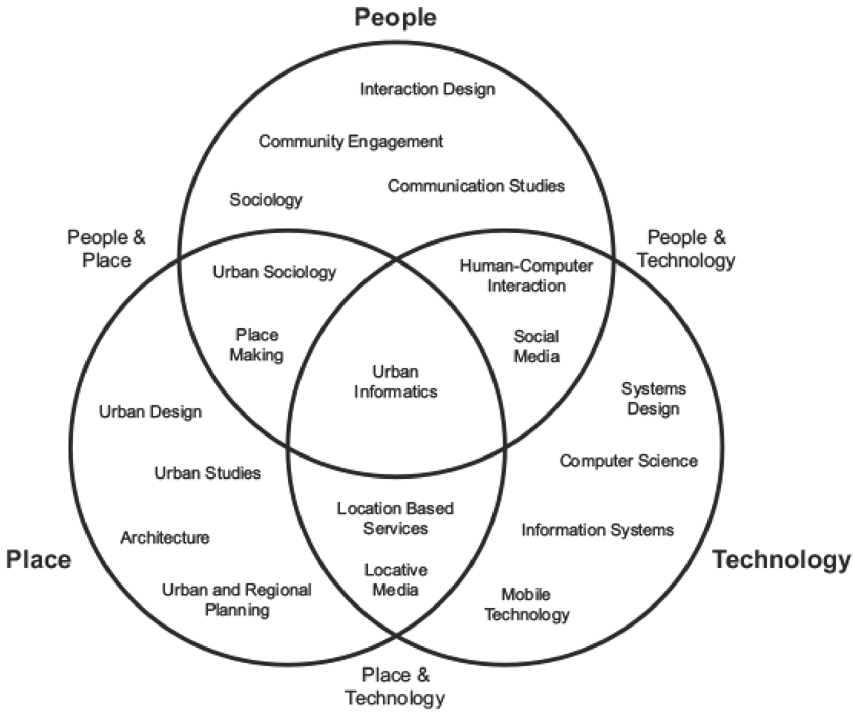

Fig. 2. Urban informatics situated within its main focus areas (Foth *et al.*, 2011). Copyright MIT Press.

The framework presented by Kuutti (2009) on the relationship between design and HCI asserts that designed (technological) artefacts are mediators of *functionality*, *meaningfulness* and *economy*. Functionality refers to the immediate usefulness of an artefact based on how it functions, whereas meaningfulness indicates that an artefact is a bearer of culturally founded meanings. As economy is outside the scope of this dissertation, both functionality and meaningfulness can be seen as important for urban informatics artefacts such as interactive public displays. This challenge for design and implementation of technological artefacts as mediators of functionality and meaningfulness necessitates acquisition of prior understanding from both sociocultural practices of people as well as architectural and social aspects of physical spaces, highlighting the need for ethnography and participatory design as epistemological approaches. Especially the evaluation of new technological artefacts in these contexts requires meaningful combinations of phenomenological, as well as positivist-oriented aspects of technologically-mediated lived experiences. This is an ongoing challenge for the urban informatics research community.

Urban interaction design is motivated by the fact that continuous fusion of technology into public urban spaces is making traditional *urban planning* increasingly insufficient, necessitating the introduction of designer competence from various focus areas such as sociology, anthropology, HCI, arts and philosophy (Brynskov *et al.*, 2014). This means that urban interaction design differs from the aforementioned research areas in that it places emphasis on urban design processes, and the emphasis on interaction design brings the artistic and aesthetic aspects into design focus. The underlying motivation for urban interaction design is to *empower* multiple stakeholders not commonly associated with urban design to take an active role in shaping their future urban surroundings, a process referred to by Brysnkov *et al*. as ‘city making’.

By definition, urban interaction design reflects the complex entanglement of stakeholders as well as focus areas in the process of city making, and illustrates the various combinations of cross-sectoral partnerships that can be formed. Accordingly, it is also at the moment the most abstract of the three research fields discussed in this section. Thus, the investigation of suitable processes and models for collaboration becomes a core focus area of urban interaction design, placing more emphasis on aspects of multidisciplinary collaboration than pragmatically on any specific technologies.

Urban interaction design also makes different *communities* as one of its core focus areas. We can differentiate between three (overlapping) community types:

1. Communities of place,
2. Communities of interest and
3. Communities of practice.

Understanding how these types of communities emerge and operate and how to potentially support this with new technologies can be considered as a core challenge within urban interaction design. This is a close linking with urban informatics, where the meaningful sociocultural practice of communities, mediated by new technologies, resides within the core focus.

Based on the introductions of three emerging research areas that deal with introduction and use of new technologies in public urban spaces, the following definition for urban computing can be made for the purpose of this dissertation:

"Urban computing is the multidisciplinary design, implementation and evaluation of new technologies, applications and services that engage and empower citizens and communities to enact sociocultural practice within public urban spaces."

This definition sets the first theoretical backdrop for this dissertation, and will act as a basis for the upcoming conceptualizations in other sections of this chapter.

2.3 Appropriation and engagement

This section deals with two core concepts related to long-term adoption of new technologies into urban sociocultural fabric: *appropriation* and *engagement*. Both terms will be first introduced and discussed individually. The section concludes by illustrating how these terms situate in relation to each other, and to the larger theoretical backdrop introduced in the previous section.

Ylipulli *et al.* (2013) approached appropriation of new urban computing technologies and services from a social science viewpoint, framing appropriation as a theory used for identifying and analyzing the factors that contribute to the long-term adoption or non-adaption of new technologies. Ylipulli defined the term appropriation as follows:

"Appropriation refers to an approach in social science technology studies that strives to explain the adoption of new technologies as a part of everyday life."

In Ylipulli's definition, appropriation is understood as

"neither socially nor technically deterministic. Rather, it is a pragmatic micro-level approach trying to explain how people make sense of new technologies".

The omission of determinism in this definition implies that the use of new technologies is not imposed upon the society as a whole, but instead relies on citizens as individuals and groups taking an active role towards the new technologies. The concept of sense-making is emphasized, meaning that through appropriation, users construct a semantic understanding of the purpose and possibilities of new technologies. Thus, the non-deterministic definition of appropriation opens up new design possibilities within the new technologies, where certain design decisions can affect how this active sense-making and in a larger sense the adoption of the technology could be facilitated.

Engagement as a term can be understood in multiple ways, depending on the context it is used in. Oxford English Dictionary, for example, defines the word ‘engage in’ in the following two ways (among others):

“To entangle, involve or commit oneself in an undertaking,” and

“to enter upon or employ oneself in an action.”

While these two definitions give direction, they are still very generic. In their article, O’Brien and Toms (2008) have employed a comprehensive literature review coupled with a set of semi-structured interviews in order to give a non-exhaustive definition for engagement in relation to interactions with technologies, and thus a more suitable one within the field of human-computer interaction:

“Engagement is a quality of user experiences with technology that is characterized by

- *challenge,*
- *aesthetic and sensory appeal,*
- *feedback,*
- *novelty,*
- *interactivity,*
- *perceived control and time,*
- *awareness,*
- *motivation,*
- *interest, and*
- *affect.”*

This definition implies that engagement is a qualitative part of an overall *user experience* with a technology and that the individual traits of engagement as a whole influence whether an encounter with a technology is engaging or not. The desire for designing engaging user experiences within ubiquitous technologies on the other hand emerges from the sociotechnical transformations alluded to earlier, challenging the definitions that link user experiences to traditional definitions of ergonomics and usability, and motivating the investigations into more holistic capturing of user experience.

To link engagement to appropriation, it can be seen that urban computing artefacts providing engaging user experiences, i.e. experiences with the aforementioned qualities, likely enjoy a better response from citizens, leading to both increased use and re-use. While this theorization is rather generic, it still provides a common ground of discussion on why certain technologies are adopted as parts of everyday sociocultural practice while others are not. Both appropriation and engagement can be seen linked further to the overall *theory of diffusion of innovations*, which on a high-level strives to explain as a social process, how new innovations spread within society and are gradually adopted through discrete user segments, starting with early adopters and eventually reaching the so-called 'laggards' (Rogers, 2003).

To situate the qualitative traits presented by O'Brien and Toms to the phases of the engagement process formulated in section 1.1, each phase of the process is shortly iterated and the exemplary traits that appear relevant in the said phase are indicated. *Discovery* stands for becoming aware of a technological artefact, and issues related to form factor and appearance such as novelty and aesthetic appearance can be leveraged. *Sense-making*, especially for interactive technologies, can emerge from perception of control coupled with a suitable feedback mechanism. Finally, *interaction* can be made more immersive for example through challenges. This qualitative definition of the engagement process will be then reflected upon when discussing related models of engagement from the literature in section 2.6.2.

2.4 Evolution of methodologies

As discussed in the introduction, the vision of ubiquitous computing is driving increased blending of computation into everyday surroundings, and in the process is shifting our understanding of what constitutes a user interface to a ubiquitous computer. Due to this blending, the ways in which computational systems are evaluated must also be re-thought. In comparison to desktop environments where quantitative performance and error minimization dominate the evaluation methods, ubiquitous computing systems are more complex and more closely tied to everyday practices of humans, and thus *"generally do not yield to simple controlled experimentation"* (Olsen Jr., 2007). For this reason, human-computer interaction takes place in a much wider variation of contexts, where performance becomes one of many characteristics of user experience, and non-functional issues also have an effect. A good example of this is the evolution of mobile computing, where communication services must also respect the social contexts of communicating participants, leading for example to different mechanisms for communicating one's presence information, as well as different strategies for managing notifications (Church & de Oliveira, 2013; Ferreira *et al.*, 2014).

During the Pervasive Computing conference in 2005, Richard Sharp and Kasim Rehman coordinated the UbiApp Workshop (Sharp & Rehman, 2005), which sought new policies and practices for application-led research within the frame of ubiquitous computing. In contrast to technology-led research, which seeks new solutions from a purely technical perspective, application-led research investigates ubiquitous applications that are deeply entangled to a specific application domain and thus specific practices. This means that the application in question is motivated through existing problems within the domain, and must also be evaluated against the contexts and practices embodied by that domain. This not only calls for assistance in evaluations from humanistic sciences such as anthropologists and social scientists, but also from dedicated domain experts.

Application-led and technology-led research should complement each other in an iterative, synergistic cycle. The motivation for application-led research is that applications in ubiquitous computing need to evolve from so-called 'proof-of-concept' demonstrations, which are motivated by a need to showcase underlying technology's features, to applications and services that are meaningfully tied to existing sociocultural practices. While proof-of-concept is certainly one way to demonstrate a novel technology, this approach tends towards an abundance of potentially trivial application cases that are neither deeply tied into domain-specific problems, nor aimed at producing tangible added value to domain-specific practices. If domain experts are missing from the research process, ubiquitous computing researchers themselves often need to emulate these experts, usually resulting in sub-optimal results.

Designing and developing ubiquitous applications requires substantial time and effort. In order to reduce this effort, research projects should aim for reusable technology infrastructures, where different applications can build on the same set of technological features and applications need not thus be developed 'from scratch'. This, according to the Workshop attendants, requires a shift in focus away from application-level novelty towards good engineering practice. Edwards *et al.* (2010) have also called for increased involvement of the HCI community in creation of technical infrastructures. A practical example of this shift was the PlaceLab project (Lamarca *et al.*, 2005), which sought to establish a reusable technological foundation for location-based services. A more recent example is the UBI program and its comprehensive infrastructure for urban computing applications in downtown Oulu, Finland (Ojala *et al.*, 2011).

Concerning evaluation of ubiquitous applications, the workshop agreed that small-scale lab studies should not be the sole method of evaluation due to the radically expanded context in which the applications will be potentially used. There is a clear need for longitudinal ‘in-the-wild’ testing for ubiquitous applications in order to sufficiently evaluate added value. In this view, early lab testing should be seen as a prerequisite in preparing the application for in-the-wild tests, where the application’s ecological validity will be maximized.

As a conclusion, the UbiApp Workshop suggested the following four recommendations for application-led research:

1. Choose applications carefully, and with the help of domain experts.
2. Share technical infrastructure to reduce the development effort of applications.
3. Evaluate applications in realistic environments, meaning that lab-based testing needs to be complemented with longitudinal in-the-wild evaluations.
4. Perform comparative evaluations by sharing evaluation datasets and allowing other researchers to cross-validate data from evaluations.

In her position article, Rogers (2011) analyzed how this movement towards in-the-wild evaluations has impacted HCI and interaction design practices. A key point is that in ethnographic sense, new technologies are being created and evaluated in-situ, *“rather than observing existing practices and then suggesting general design implications or system requirements“.* In accordance with wider interaction design ethos, which deviates from pure needs-based solutions, new technological solutions that augment people, places and contexts can also aim to provoke and provide surprising outcomes. As a result, *“opportunities are created, interventions are installed, and different ways of behaving are encouraged. A key concern is how people react, change, and integrate these in their everyday lives“.* Design-wise, the solution-oriented objective of improving everyday practices of life has recently been complemented with the more disruptive viewpoint of *“experimenting with new technological possibilities that can change and even disrupt behavior”*. In this argumentation, Rogers can also be seen as referencing her earlier manifesto on engaging ubicomp experiences (Rogers, 2006).

This progress is also reflected in user experience evaluation practices, where the focus is shifting *"from work towards leisure, from controlled tasks towards open use situations, and from desktop computing towards consumer products and art"*, and where *"[e]motions, enjoyment and aesthetics are the most frequently assessed dimensions"* (Bargas-Avila & Hornbæk, 2011). The similarities of these statements to the qualities of engaging user experiences given in section 2.3 are evident. Much of this progress is enabled through the availability of various off-the-shelf technological platforms that package necessary computational features together with an associated application development kits, allowing application designers to work with domain-specific issues[3]. This development is directly in line with the earlier issue of improving availability of technological infrastructure.

Despite being more costly and time-consuming than lab studies, in-the-wild evaluations bring added value and often uncover issues not evident in laboratory environment (Rogers *et al.*, 2007). Sellen *et al.* (2009) asserted that *"[new] research methods must capture how the use of technologies may unfold over time and in different situations"*, while Greenberg and Buxton (2008) asserted that *"[a certain level of] cultural and technical readiness is needed before a system can be deemed 'successful'"*. Within in-the-wild studies, people make sense of and appropriate new technologies on their own terms, for their own situated purposes and without active on-site scaffolding from researchers. In this setting, both extrinsic and intrinsic motivations become key issues: Technology is no longer appropriated as part of a lab study routine and with the primary goal of pleasing the on-site researchers, also referred to as *demand characteristics* (Brown *et al.*, 2011), but instead because it provides added situational value or because it provokes curiosity and challenge through its design. This complex intertwining of functional and non-functional issues of technology without researcher scaffolding also produces data from where it is almost impossible to isolate all causes and interdependencies of an observed effect. This means that data analysis of in-the-wild studies is radically different from that of a structured lab study data. To act as a working compromise, Johnson *et al.* (2012) suggested different roles that on-site researchers can take in an in-the-wild evaluation, for example encouraging interaction and explaining complex functionality. This helps in building rapport with participants and can help in revealing otherwise imperceptible details, but it

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[3] An example of this development is the Arduino Kit, http://www.arduino.cc

also demands reflexivity from researcher's side, both in terms of original aims as well as the role the researcher has within the research process.

As a third aspect beside design and evaluation, Rogers (2011) considered the role of theories in in-the-wild settings. Rather than reapplying 'clean' theories resulted from replicated and validated lab studies by making predictions and measuring outcomes, in-the-wild theories should aim to better explain the interdependencies between design, technology and appropriation. This also calls into question the re-examination of the utility of theories in the face of complex real world situations. According to Rogers, we can both import theories already tested in real world situations into the field of interaction design, as well as begin to craft new, so-called 'wild theories' to explain behavior and appropriation in-the-wild. Theories such as embodiment and embodied interactions, the felt experience theory, proxemics, and ecological rationality all aim towards capturing the overall technological experience in a richer way than a fixed set of independent and dependent variables. Completely new theories can be heuristically informed by existing theories, while utilizing a bottom-up approach according to grounded theory practice. In this perspective, this dissertation is aiming to lay foundations for a grounded theory on engagement and agency of multipurpose public displays in public urban spaces.

Gaver *et al.* (2009) raise an interesting facet to this discussion by claiming that *"systems built to support open-ended interpretation and appropriation can fail. This has been something of a dilemma in the past since, if participants interpreted prototypes differently than expected, this could be taken as evidence for the system's interpretative flexibility"*. To reinforce this claim, Gaver *et al.* took into focus their recent technological deployment into selected domestic environments and critically dissected this deployment to formulate a set of 'symptoms' for inferring whether a deployment has succeeded or failed. In the following paragraphs, each of these symptoms will be concisely discussed.

Engagement with the system manifests itself through enthusiasm regarding experiences with the system, persistence in use, emerging suggestions for improvement, showing the prototype to friends and acquaintances and discussing about it, and expressions of agency and ownership towards the prototype. These manifestations can be linked to the qualities of engaging user experiences listed in section 2.3 (O'Brien & Toms, 2008). As an example, expressions of agency and ownership can be linked to interactivity and perceived control. Strong presence of these traits in people's everyday practices indicates a successful deployment, whereas lack in these traits is symptomatic for a failed deployment.

Reference happens when people discuss the prototype through references to other technologies or experiences that they like. When this practice continues long enough, it carries a potential of *"constituting a category of valued experiences that could include the prototype and thus allow its appeal to be understood and articulated"*. When reference does not happen, it potentially implies that users of the prototype technology are having difficulties in adopting the technology as part of their accumulated body of knowledge. Reference is directly related to the process of sense-making introduced earlier, as well as to mental models, discussed in detail in later sections.

Accommodation directly refers to the degree to which people integrate successful technology prototypes into their existing everyday practices. This degree was also earlier referred to as *domestication* (Birnbaum, 1985). Later in this dissertation, the term appropriation will be used to cover both accommodation and domestication. As prototypes are meant to offer functionality and content not normally experienced by users, accommodation is a real process that must take place if people are to engage the technology not as explicit acts of curiosity but as parts of everyday practices. It is fairly obvious that if accommodation does not take place, the deployment of technology will remain isolated from everyday life and thus becomes more of a curiosity. Accommodation is a highly important feature of new technologies, especially when starting to consider different business model and valuation alternatives.

As the last symptom, Gaver *et al.* (2009) listed *surprise and insight*, which *"are neither properties of the system per se nor of the people who use it, but instead characterize the relationship between the two"*. Surprise and insight are key issues in motivating sustained interactions with the prototype, and thus keeping the accommodation process ongoing. Surprises are any features or content of the prototype system not encountered on previous interactions, and can lead to new insights regarding the system, potentially enabling new references to be made. This is especially beneficial for interactive technologies that are designed for exploratory interactions.

As a final analysis for this section, the three main paradigms of HCI are briefly covered, and the evolution of HCI research towards in-the-wild evaluation contexts and a multidisciplinary approach is illustrated. This is especially to acknowledge the widening of disciplinary focus from the original combination of computer science and psychology. HCI as a field of research and practice is largely understood through sequential emergence of three distinct paradigms (Harrison *et al.*, 2007):

1. Human factors,
2. Classical cognitivism, and
3. Phenomenologically situated.

Kuhn's (1962) classical theory of scientific revolutions originally defined paradigm as the time when one phenomenon and its interrelated questions and research methods prevail, to be at some point overthrown by another phenomenon with new associated questions and methods. However, due to the interdisciplinary nature of HCI, it can be too restrictive to discuss one dominant phenomenon at a single time, and this has lead for example Agre (1997) to define paradigm in HCI as *"the underlying metaphor of interaction used in discussion"*. Generalized into technical sciences, Agre's theory suggests that technical fields are structured around metaphors that guide the questions that are interesting to ask and methods for arriving at answers to them. In the case of metaphors, certain phenomena tend to be brought into the center of investigation while marginalizing others. Additionally, while Kuhn's theory suggests an absolutist metric where one paradigm is correct and others wrong, Agre's metaphors can exist side-by-side without the need for mutual exclusivity.

The first paradigm, *human factors* is a pragmatic approach to identifying problems in industrial systems and in ergonomics. Applied to HCI, human factors conceptualize interaction as a *form of man-machine coupling*, where pragmatic solutions are proposed for optimizing the physical fit between the man and the machine. This metaphor brings tangible problems into focus and suggests positivist and evaluations for them. The second paradigm, *classical cognitivism*, has been a dominant metaphor in HCI for a significant period of time. The central idea, proposed by Winograd and Flores (1986), is that of a human mind and the computer interacting as *coupled information processors*. Based on established deep analogies between human information processing and computational signal processing, the primary task within the second paradigm becomes that of enabling *communication between the machine and the human*. As a separation to human factors, classical cognitivism takes as its core focus *a formal model*, abstracted from the conceptualization of coupled information processors, and forming a generalizable basis. Since these models allow operations to be measured in terms of goals accomplished, they present HCI researchers a systematic tool for comparatively analyzing different designs, and thus follows closely the positivist-reductionist approach of computer science.

While these two metaphors cover a wide area of HCI knowledge and may easily lead one to reject additional metaphors, over the last few decades, many approaches have emerged that poorly fit neither of the established metaphors. In a third, *phenomenologically situated* metaphor, the researcher is in general not seeking a single, generalizable design implication that would justify the exploration, but would instead use the so-called *thick description* to "*instigate a design process whose outcomes were indeterminate, yet satisfactory"* (Dourish, 2006b). As stated by Harrison *et al.* (2007), *"under the third paradigm, the context ideally includes the totality of experience, including aspects that may be irrelevant to the immediate goal of the interaction. […] a consequence of this is that context is a central component not only to the problem (if any) but also to design and evaluation"*. These ideas embodying the third paradigm of HCI closely resemble those put forward by Rogers in seeking theoretical basis for in-the-wild evaluations. This dissertation thus concludes that not only are multidisciplinary in-the-wild methods recognized within the academia, but that they are crucial in deeming contemporary and future urban computing technologies as (un)successful.

2.5 Public displays as urban computing artefacts

Signage, meaning collective understanding of signs used to convey information in public, has been a cornerstone of how citizens perceive and make sense of public urban spaces for centuries. Signage is always delivered through different technologies of *public displays*, and for centuries, paper and its derivatives were the main medium. The first electronic public display can be traced back to the year 1928, when the Motogram (later nicknamed as 'zipper'), consisting of a continuous array of incandescent light bulbs, was installed on the outer surface of One Times Square building in New York City, and circled the entire building (Sagalyn, 2001, p. 40). As individual bulbs acted as pixels, the Motogram allowed dynamically changing textual information to be shown in a sliding format within the display space. Similar zipper-style public displays can be found from Times Square today, honoring the tradition initiated by the Motogram.

From the Motogram onwards, different electronic public display technologies for signage have been introduced, driven mostly by spaces with crowds such as sports stadiums and airports. During the 2010s, display panels based on liquid crystal technology (LCD) have become cost-effective in terms of unit price, and are expected to be gradually substituted by different technologies based on light-emitting diodes (LED). Several projection-based technologies are also available. During the last three decades, especially the emergence of LCD technologies has been a key enabler for contemporary *digital signage*, i.e. urban signage delivered through electronic digital displays. Digital signage has several benefits in comparison to paper-based signage, including potential capacity to display video content, and the ability to remotely and dynamically manage content based on time-of-day as well as in terms of which locations show which content.

This emergence of digital public displays started to attracted attention from art and academic communities, which begun to incorporate these display technologies into their designs. Among the first examples is an art installation called 'Hole-in-Space', where artists Kit Galloway and Sherrie Rabinowitz connected two streets in New York City and Los Angeles with a real-time, full-duplex audio/video connection, essentially creating a *virtual window* between the two locations (Galloway & Rabinowitz, 1980). This artistic deployment gave rise to a research area known as *media spaces*, where different locations are connected with an always-on audio/video link. Research has indicated that while ongoing conversations through media spaces can emulate co-located conversations well, media spaces poorly support the formation of conversations due to the insufficient inclusion of necessary social 'back channels' (Bly *et al.*, 1993; Fish *et al.*, 1990). As Weiser formulated his visions of ubiquitous computing, public display research turned to situated information provisioning and so-called ambient displays, meaning framing of everyday artefacts as displays of information (Finney *et al.*, 1996; Houde *et al.*, 1998; Mankoff *et al.*, 2003; Prante *et al.*, 2004). A famous example of ambient displays was the 'dangling string' that was refurbished with an electronic servomotor and framed as a display of network activity in one's attentional periphery (Weiser & Brown, 1997).

In the beginning of 2000s, academic public display systems focused on situated communication and raising awareness of the presence of others. Examples included so-called 'door displays' that would act as a digital counterpart for asynchronous messaging and signage next to an office door (Cheverst *et al.*, 2005; Cheverst *et al.*, 2003), and systems supporting social interactions within a community (Brignull & Rogers, 2003; Churchill *et al.*, 2003; Greenberg & Rounding, 2001). The proliferation of smart phones also saw academic experimentation with mobile devices as input devices for public displays (Ballagas *et al.*, 2006; Boring *et al.*, 2009). By the 2010s, both commercial and academic public display installations have evolved to interconnected networks of digital displays, increasingly utilizing web-based technologies for the production, management, distribution and rendering of digital content. Additionally, the academic side is experimenting with different models of interactivity, with new use cases, and with the balancing of commercial and non-commercial content. Examples of contemporary real-world deployments done by research institutions include the UBI-hotspots in Oulu, Finland (Ojala *et al.*, 2012), as well as the eCampus system in Lancaster, UK (Storz *et al.*, 2006). The UBI-program has defined the concept of multipurpose public display, i.e. MPD, to specifically denote the emergence of new use cases. Adhering to the issues discussed in this chapter, Alt *et al.* (2012) discuss the evaluation of contemporary public display prototypes and state that *"there is an emerging need for both practitioners and researchers, to understand how to best evaluate public displays with regard to effectiveness, audience behavior, user experience and acceptance, and social as well as privacy impacts"*.

As can be seen from the evolution of public display prototypes, more and more functionality as well as more various aims have been gradually brought into design. Thus, public display technologies are academically perceived as a platform for experimenting with use cases that clearly go beyond the basic framing of this medium in delivering passive digital signage. These new use cases link public display research to the larger theoretical frame of urban computing: By considering public displays as a new urban computing technological artefact subjected to designs that can empower citizens and help enact sociocultural practice, the role of the display artefacts themselves is being disruptively re-thought. This re-thinking introduces complexity to design processes, meaning that a systematic way of capturing design possibilities and guidelines, *a design space*, needs to be constructed. This new design space for public displays is the very focus of the next section.

2.6 Design space for interactive public displays

Design spaces are useful tools and mappings for designers and developers of complex interactive technology, because they strive to systematically encapsulate and illustrate both the constraints and the possibilities associated to a specific technology, uncovered through previous research. As examples, Card *et al.* (1991) present a morphological analysis of input devices in a form of a design space, and Ballagas (2006) reports the possibilities of smartphones as ubiquitous input devices through a design space. This section of the dissertation will first review contemporary models and guidelines for interactive public displays in detail, after which the findings are drawn together into a layered design space. When discussing each layer of the design space, the impact of that respective layer to the engagement process presented in the introduction will be highlighted, revealing insights related to the research question and the objectives of this dissertation. More specifically, the notions of mapping and arbitration will be introduced to the design space when discussing multipurpose public displays as the final layer of the design space. The constructed design space then acts as an analytical basis for discussing the case studies in Chapter 3.

The design space for contemporary interactive public displays can be seen as comprising from a set of complementary layers, with the features of traditional passive digital signage situated at the bottom layer. From this base, interactivity creates a complementary layer with features of emerging interaction at its core. The framing of interactive public displays as internetworked urban computing artefacts creates the final complementary layer. As the layers are complementary in nature, each layer inherits the features and issues from all layers below it. The individual works discussed as the basis for this design space are also referred in their own context as design spaces, so the final design space should be seen as a complementary whole from several individual design spaces with differing foci.

2.6.1 Layer 1: All public displays

The first layer of the design space deals with features common to all public displays, and thus focuses on factors of size, form as well as positioning within a physical space. Terrenghi *et al.* (2009) discussed how different display form factors afford different spatial arrangements of viewers. By using the comfortable visual angle of 30° to 45° of the human eye as the basis, a public display tends to create a natural viewing area at a distance in relation to the physical size of the display. This is also the case with domestic TV sets, and for example TV manufacturer LG recommends a distance of 3.35 meters (11 feet) for a display panel with a diagonal size of 1.27 meters (50 inches). Thus, the design space is informed by the relation between the physical size of a display panel and its associated comfortable viewing distance.

Likewise to physical size, the spatial positioning of the display is a key factor within all public displays. In their article on display blindness, Huang *et al.* (2008) empirically concluded that displays placed either too low or too high with respect to average height of human field of vision receive significantly less attention than those placed on the eye-level. This is also dependent on distance because the field of vision widens in relation to distance. Another factor within the spatial positioning is the angle of the display in relation to major *people flows* within the physical space. Displays positioned directly in front of people flows attract more direct attention, while displays placed orthogonally to these flows attract more peripheral attention. This factor connects the public display design space closely to two quantitative theories within architecture that deal with visibility, namely *space syntax* and *isovist views* (Dalton *et al.*, 2010).

Additional factors related to the physical form factor of public displays include the orientation (portrait or landscape), different chaining or matrix configurations of display units, as well as display panel forms that differ from traditional non-curved rectangular shapes, meaning for example cylindrical shapes. Ten Koppel *et al.* (2012) investigated different chaining configurations of six public displays each in portrait orientation, namely flat, hexagonal and concave. Their design space was based on the concepts of *nimbus* and *focus*, applied both to the users of the displays, as well as to the display artefacts themselves. Nimbus refers to a sub-space within which a person projects his/her presence, while focus represents a sub-space within which a person projects his/her attention. Applied to the display artefacts, nimbus means the area from which the screen contents are visible, whereas focus means the area where interactions with the displays can be performed (Figure 3). The findings of Ten Koppel *et al*. indicate that display discoverability increases when the nimbus, i.e. visibility of screen real-estate, increases. Through this definition, Ten Koppel *et al.*'s work also links tightly to isovist views.

Wallace *et al.* (2014) investigated the bezels that are formed within matrices of display units from the viewpoint of visual search, and discovered that in laboratory conditions, the presence of bezels may act as visual anchors. This suggests that important visual elements could be anchored or otherwise placed near the bezels in order to improve their discoverability within the overall screen real-estate. Beyer *et al.* (2011) investigated a prototype of a cylindrically shaped public display in a laboratory setting, and discovered that the physical form factor invites people to more actively move around the display. This indicates potential within so-called transitional spaces such as streets, where people can be reluctant to stop in front of the display and prefer to maintain a walking speed.

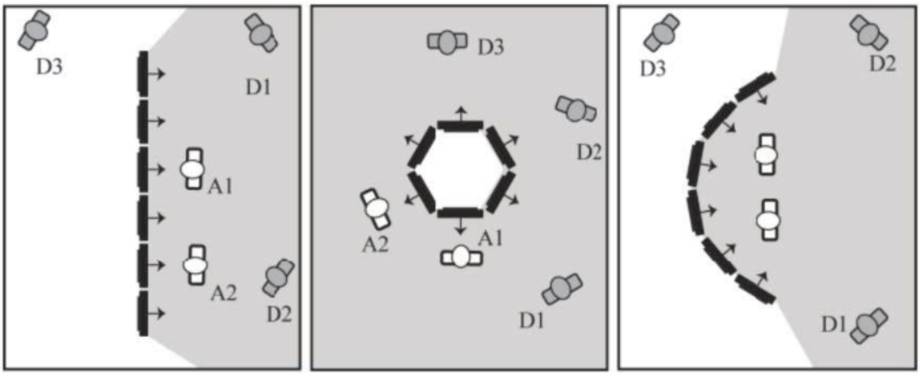

Fig. 3. Examples of display nimbus (gray area) embodied by three configurations of six chained public displays presented by Ten Koppel *et al.* (2012). The second configuration implements the cylindrical concept presented by Beyer *et al.* (2011) through chaining of flat display panels. Copyright ACM Press, 2012.

Impact on the engagement process

On layer one, the engagement with public displays consists solely of a *viewing experience*, so the engagement process comprises the opportunistic discovery of a display, followed by sense-making related to the content being shown. This brings optimizing of the display visibility into focus within the design space, dictated by optimizing the isovist view associated to a display. In the terminology of Ten Koppel *et al.* (2012) , this means optimizing the nimbus of the public display in a given public space. Another aspect within the focus of the design space is accommodation of simultaneous viewers within a comfortable viewing distance, dependent on the physical size of the screen real-estate.

2.6.2 Layer 2: Interactive public displays

The second layer of the design space deals with public displays providing interactive facilities. As alluded before, these displays inherit all the aspects from the first layer, and add new ones that are applicable only to interactive displays. One example consequence of this inheritance is that if an interactive public display is supported solely with a touch-based interaction technique, the interactive content should be placed within the comfortable viewing area that is formed from the distance of comfortable pointing to the touch panel. In cases of very large wall displays, this means designing smaller, virtual interaction areas.

Thus, touch-based interactive public displays need to adhere to the limitations of the comfortable viewing angle presented on layer one. Other example of this inheritance is that the findings by Wallace *et al.* (2014) regarding display bezels structuring visual search can be leveraged for placement of menus and other key interactive elements in the case of interactive public displays.

The key difference within all interactive public displays is that the gradual process of a bystander becoming an active participant within the interaction needs to be modelled according to certain heuristics, so that the display can be designed to invite and afford interactions. While interactive public displays and related research have existed, especially within the Computer-Supported Co-operative Work (CSCW) domain (Greenberg & Rounding, 2001; Huang *et al.*, 2006) and selected semi-public spaces (Izadi *et al.*, 2005), this dissertation explicitly sets its focus to works that have identified aspects of how interactions with public displays emerge in public contexts, and how the design of the display artefact itself can contribute to this. Additionally, the focus is on models where interactions emerge from opportunistic perceiving of an interactive public display, and where social conventions are the main source for arbitrating interactions between citizens.

Müller *et al.* (2010) have drafted a set of requirements as well as a design space for interactive public displays, and their work acts as the base for the second layer of the design space in this dissertation. The requirements essentially state that approaching the display should be designed in separate but possibly overlapping *phases* that are guided by the factors of *attention* and *motivation*, and that interaction in a public context should be accounted for in the design. The design space on the other hand consists of different *mental models* that the display design can attempt to evoke, as well as of different *interaction modalities* that can be utilized to carry out the interactions with the display. These aspects are individually explained in forthcoming sections.

Modelling emerging interactions with interactive public displays gradually through discrete phases was first suggested by Brignull and Rogers (2003) within the evaluation of their Opinionizer prototype. Based on empirical observations of groups interacting with the prototype, three ‘activity spaces’ were identified: peripheral awareness, focal awareness and direct interaction. First two spaces consist of bystanders aware of the presence of the display, separated on whether they are directly paying attention to the public display or not. Direct interaction consists of those individuals that actively interact with the display through the designed interaction mechanism, in this case, through a separate laptop connected to the public display. Due to the deployment location of a conference socializing event, it was probably not meaningful to identify bystanders that would not have been aware of the display's presence. Compared to the engagement process formulated in this thesis, both peripheral and focal awareness relate to how the display artefact is discovered, while focal awareness and especially the observation of others interacting is key in the sense-making of the display's functionality. This focal awareness can then subsequently motivate bystanders enough to lead to active engagement of the display by interacting with it.

Brignull and Rogers' main empirical insight was that in the presence of an interactive public display, people self-organize into these discrete phases, and that the design of the interactive public display itself can play part in how individuals cross the thresholds from one phase to another, starting from peripheral awareness and potentially progressing to the phase of direct interaction, thus enacting social practice through the display, in this case, contributing opinions to the public display for others to see and react upon. An important guideline is so-called *vicarious learning*, i.e. how interaction as a mechanism can be made public so that others can learn through observations and thus build up their confidence for crossing the thresholds of participation. This behavioural pattern was labelled by Brignull and Rogers as 'the honeypot effect'. Making interactions visible is also one of the key findings within interactive public displays in the CSCW domain (Huang *et al.*, 2006).

Vogel and Balakrishnan (2004) derived a set of design principles and an interaction framework for interactive public displays, and demonstrated these conceptualizations through a laboratory prototype. This work can be seen as extending the conceptualizations derived by Brignull and Rogers (2003), and acting as basis for the work of Müller *et al.* (2010). The design principles are briefly re-iterated here:

- *Calm aesthetics*: As interactive public displays become parts of the spaces they inhabit, there is a trade-off between an overly reactive and too static behaviour of the display based on people's presence.
- *Comprehension*: While certain ambiguity in presented content can invite users to interact in an exploratory fashion, people should be able to gradually discover meaning from the content while progressing with the interaction.

- *Notification*: The display should utilize socially acceptable methods for notifying and communicating interactivity to passers-by.
- *Short-duration fluid interaction*: Interactions should be designed to be short in duration, support mostly quick information querying, and not require explicit sign-in or sign-out activities.
- *Immediate usability*: The display should encourage learning both through exploration as well as through observation, i.e. the vicarious learning defined by Brignull and Rogers.
- *Shared use*: The display should allow multiple simultaneous independent users, collaborative use, combination of use and viewing, or some combination of all these.
- *Combining public and personal information*: The display should show the so-called *harmless personal information* when possible, while still continuing to show public information to viewers. Here, a central design tenet is the implicit formation of a semi-private interaction space through bodily occlusion.
- *Privacy*: The display should at all times allow users to control what personal content is shown, if any, and how.

The interaction framework presented by Vogel and Balakrishnan consists of four phases: ambient display, implicit interaction, subtle interaction and personal interaction (Figure 4). The ambient display phase can be considered equivalent to peripheral awareness, where passers-by are aware of the display but are not paying active attention to it. Implicit interaction on the other hand translates to focal awareness, and according to the design principles, this is the phase when the display can attempt to invite interaction from the user. Subtle interaction can be understood as any kind of explicit interaction with the display where personal information is not yet shown. Finally, personal interaction is interaction where personal information is also included, and the key tenet here is the bodily occlusion, which in Vogel's design provides the necessary level of privacy and allows the so-called harmless personal information to be shown.

Vogel and Balakrishnan's model compares to the engagement process formulated in this thesis as follows: discovery of the display artefact is divided between the phases of Ambient Display and Implicit Interaction, depending on whether the display remains within the peripheral attention or becomes an active focus of the passer-by. Both sense-making and interaction phases overlap in the three interaction phases of Vogel and Balakrishnan's model, suggesting that once the interactivity has been successfully discovered, the sense-making takes place through gradually designed phases of engaging with the display.

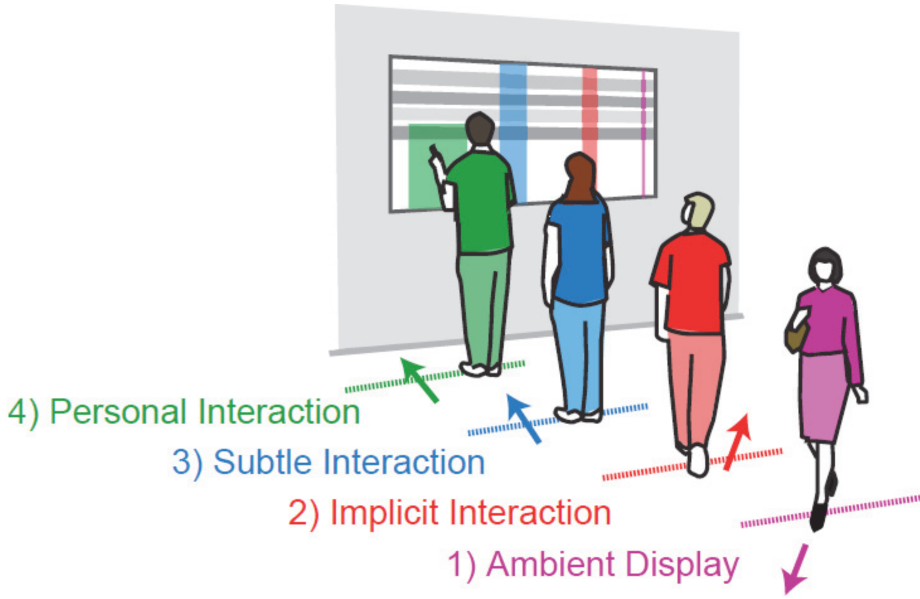

Fig. 4. Four-phase interaction framework by Vogel and Balakrishnan (2004). Copyright ACM Press, 2004.

In interpreting the design principles and the interaction framework presented by Vogel and Balakrishnan, it should be remembered that the prototype was implemented and evaluated solely in laboratory conditions, and as such, it takes no stance as to what its deployment context could be. Based on the design principles, it seems that the prototype could be aimed mostly for CSCW environments. For this reason, although the design principles and the interaction framework are presented here in their entirety, these should be taken as recommendations that further concretize aspects also evident in Brignull and Roger's model, such as levels of awareness and vicarious learning.

As a final model of interaction phases, the *audience funnel* concept (Figure 5), derived through empirical observations by Michelis and Müller (2011), is discussed. Their prototype was called Magical Mirrors, and was deployed at

Berlin city centre. Magical Mirrors act as augmented mirrors, identifying movement within the mirror image and augmenting the identified movement trajectories with ephemeral graphics. Regarding formalization of interaction models, Michelis and Müller state that *"there seems to be a kind of disconnect between the ad hoc frameworks and the observation-based frameworks of interaction. The ad hoc frameworks have never been tested with a larger number of users, and the observation-based frameworks have been investigated with systems that do not actually adapt to the user in different phases"*. Michelis and Müller conclude that more quantitative metrics are needed for evaluating interaction frameworks with interactive public displays, and for this end they present and utilize the so-called *conversion rates*, i.e. quantitative percentages that indicate the fractions of the overall people flow that cross the thresholds of the interaction framework.

The audience funnel contains the same phases as Vogel's interaction framework, and adds two additional steps: multiple interactions and follow-up actions. Multiple interactions take place when a person engages in direct interaction with more than one display within an installation, whereas follow-up actions augment the interaction setting for example by people taking photos of themselves interacting, thus wanting to reinforce and emphasize the engagement. Additionally, the arrangement of multiple displays with identical design adjacently allowed the observation of the so-called *progressive approach*, where successive interactive displays gradually raise the attention and motivation of the passer-by so that the display interacted with is not necessarily the first one encountered. This allows passers-by to accommodate and comprehend the interaction model while walking next to the deployment. This design bears similarities to the method of increasing the total nimbus and focus areas by chaining displays (Ten Koppel *et al.*, 2012).

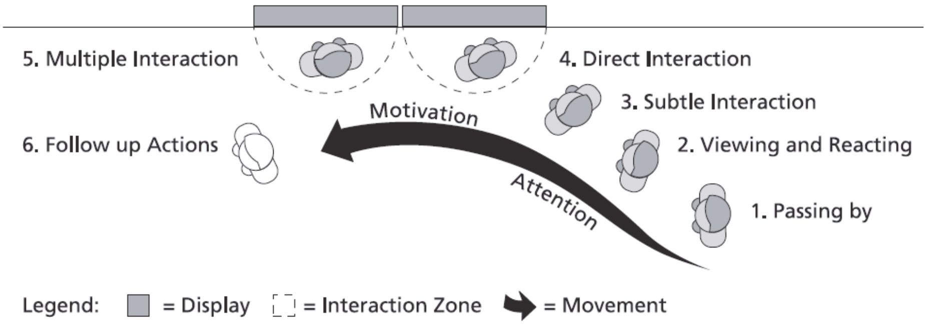

Fig. 5. The audience funnel (Müller *et al.*, 2010). Copyright ACM Press, 2010.

Attention and motivation are central for inviting passers-by to cross the thresholds within the designed interaction frameworks and progress towards interactions with a public display. As Vogel alluded, designed displays need to balance between too static and too distracting ways of gathering attention. As evidenced by the audience funnel and especially the successive Looking Glass prototype (Müller *et al.*, 2012), the utilization of *personal mirror image* acts as a strong attentional cue, while not being overly distractive for the rest of the surrounding environment. Other more explicit ways to capture attention include for example different *call-to-action* texts, which explicitly invite passers-by, once they are discovered. Kukka *et al.* (2013) discuss and evaluate different call-to-action texts in terms of colouring, animation and textual versus iconic representation. They discovered that static, coloured text works best overall.

Müller *et al.* (2010) present several alternatives for raising the motivation of passers-by. Potential users can for example be presented with a challenge that needs solving, or given at least a subjective sense of control over the display. Agamanolis (2003) has stated that *"half the battle in designing an interactive situated or public display is designing how the display will invite interaction"*. Curiosity is effective, especially in exploratory use. Presenting different choices can motivate, although the potential user must first be made familiar with the alternatives of the choice, meaning that this mechanism could be used later in the interaction. Using different metaphors as the design basis for interactive public displays, one can use fantasy and imagination to motivate passers-by for interaction, in a sense of temporarily letting loose from mundane reality. Finally, collaboration presents a design opportunity where in-situ cooperation and competition aspects designed into the interaction can invite and motivate passers-by to interact.

As interactive public displays are by definition malleable by design, they can be made to evoke commonly known mental models in the minds of the citizens, as well as have potential to give rise to completely new mental models over time. The use of well-known mental models can significantly decrease the amount of sense-making required prior to crossing participation thresholds. Unfortunately, this can also mean that since domestic TV sets are usually the closest semantic match for most people, public displays get often associated with the mental model of a 'public TV' (McCarthy *et al.*, 2009). It can be expected that the emergence of so-called 'smart TVs' with interactive features will alleviate this association, along with the current display-based smartphone paradigm. Müller *et al.* (2010) have listed some examples of mental models that can be evoked through public display design:

- *Poster* comes perhaps closest to the traditional idea of passive digital signage, and can be designed to be an interactive counterpart to a traditional (paper-based) poster, suitable for glancing and browsing of information. The CityWall prototype is an interactive poster designed for browsing of Flickr images, implemented through a multi-touch interactive panel (Peltonen *et al.*, 2008).
- *Window* mental model can be used to simulate a live view to remote, possibly virtual, location. Using public or semi-public displays as continuous windows is basically the conceptual foundation for media spaces discussed earlier (Bly *et al.*, 1993; Fish *et al.*, 1990). Unlike traditional windows, public displays can simulate either one-way or two-way windows.
- *Mirror* was already earlier explained as a highly effective way for capturing attention of passers-by (Müller *et al.*, 2012). A potential weakness in mirror-based mental models is that it may be difficult to have the interaction proceed further from the interactive exploration of one's mirror image.
- *Overlay* models are based on projectors, and allow projected images to be overlaid on any surfaces. As an example, *pico projectors* are capable of projecting graphics on any solid

surfaces, and by nature overlay the original surface with a digital representation (Dachselt *et al.*, 2012). Implementing accurate interactivity to the overlay can however be more problematic than to a physical display panel.

Finally, Müller *et al.* raise different interaction modalities as a central tenet of a design space of interactive public displays. There are many ways to implement interactivity, and designers should carefully think which modalities best fit a given deployment of a public display. On a high level, the interaction modalities can be divided into *implicit* and *explicit*. According to a widely accepted definition, implicit interaction is *"an action performed by the user that is not primarily aimed to interact with a computerised system but which such a system understands as input"* (Schmidt, 2000). As a counterpart, explicit interaction comprises all actions performed by the user that are aimed to interact with a system and subsequently interpreted as input. What this means for interactive public displays is that the first steps of interaction phases are usually implemented as implicit interaction in order to have the passer-by acknowledge the interactivity, and to invite further interaction.

Different aspects of physical presence such as distance, orientation or movement, commonly referred to as *proxemics*, are viable options for implicit input (Greenberg *et al.*, 2011). More specifically, Marquardt and Greenberg (2012) discuss how five operational dimensions of proxemics, *distance*, *orientation*, *movement*, *identity* and *location*, can be leveraged in design in order to reveal interactive facilities of technological artefacts (Figure 6). Marquardt *et al.* (2012) also present an interaction pattern called *gradual engagement* for proxemics-based implicit behavior of interactive devices. The pattern is aimed for facilitated information exchange, and consists of three phases: *awareness*, *reveal* and *transfer*. Dostal *et al.* (2013) discuss two case studies where proxemics are leveraged to display multiplexed information for multiple simultaneous users on a single display. Finally, as every implicit input mechanism can be explicitly exploited, proxemics is no exception. Greenberg *et al.* (2014) discuss dark patterns in proxemics, and for example conclude that proxemics can be accidental, that it is sometimes difficult to opt-out from interactions, and that multiple meanings and potentially ambiguous ownership regarding physical space can be problematic.

Fig. 6. Five dimensions of proxemic interactions (Greenberg *et al.*, 2011): distance, orientation, movement, identity and location. Copyright ACM Press, 2011.

For explicit input, division can be made between touch-based, mid-air-based, and mobile interaction modalities. Touch can be single-point or multi-point, and interaction designs can differ accordingly. Arguably, single-point touch screen reduces collaborative aspects on public displays, as one person needs to take 'the driving seat' while others can interact indirectly via this proxy person. The CityWall experiment by Peltonen *et al.* (2008) provides empirical examples of how collaboration and conflict management can be handled by social conventions in a case of a multi-touch display.

Recently, mid-air gestures have received attention as an interaction modality for public displays (Jurmu *et al.*, 2013; Kurdyukova *et al.*, 2012; Walter *et al.*, 2013). Mid-air gesturing can be hypothesized as a convenient bridging from implicit to explicit interaction, as it is based on physical presence in front of the display. Additionally, mid-air gestures are by nature performative, and thus maximize the vicarious learning. Finally, mid-air gestures still have a lot of room for creativity, giving designers a variety of options in designing interactions. However, mid-air gestures also carry a host of problems. Norman (2010) discusses gestural interfaces from a variety of viewpoints, and highlights as a main challenge that gestural interaction does not yet have widely accepted conventions that could facilitate wider uptake and give this modality a solid ground for design. Additionally, it is difficult to define trajectories and magnitudes of gestures precisely, making it harder to learn 'correct' gestures, i.e. ones that the display system interprets correctly. According to Norman, however, gestural interfaces will most likely develop in a bottom-up fashion through empirical prototypes and experimentation, rather than through theorized top-down specifications.

Mobile interaction with public displays also has a wide variety of options. Ballagas *et al.* (2006) provided a comprehensive survey of mobile input techniques from the 'pre-iPhone' era. They also highlight *serendipity* in cases of mobile input, meaning that setting up and tearing down control sessions between the mobile device and the public display should be as easy and as fast as possible. This directly points towards methods other than for example manually inputting IP addresses and socket ports in order to establish connections. Another advantage of mobile input is that the user can rely on a personal, familiar device for provisioning of input, instead of going through a learning curve with a potentially foreign user interface in-situ. Boring *et al.* (2010) discuss a prototype called Touch Projector, whose main idea is to export the touch-based controls of a full-touch smartphone to the public display in real-time, through live video. Rashid *et al.* (2012) have investigated the different configurations of input and output in settings that combine a mobile device and a public display from the cognitive load viewpoint. Their insights indicate that in order to reduce attention shifts and to keep the visual and input spaces separate, the visual output should not be duplicated on both devices. This suggests that the mobile device should embody a role primarily on the input, while the public display should embody a role on the output of the interaction task. Kurdyukova *et al.* (2012) have arrived to similar conclusions from the viewpoint of privacy in terms of personalized public displays, highlighting the fact that mobile-based techniques both give users the opportunity to be discrete, as well as to more flexibly choose the position in front of the display when interacting. This flexibility of movement is especially pronounced in commercial installations like the McDonald's Pick'n'Play (2014), where a very large interactive public display features pong games where two players connect to the public display with their mobile devices.

An inherent trait of interactive public displays is that the interaction takes place in a public context. This means that interactive public displays can also be analyzed from the viewpoint of how interaction in the public should be designed. Kuikkaniemi *et al.* (2011) list a set of design challenges for future interactive public display installations. Of the seven challenges (multiple users, implicit interaction, adaptive screen, interaction sessions and lifecycle, screen form and shape, environmental factors and privacy), most have already been discussed in this chapter. Adaptiveness of a display can be an interaction-related as well as content-related design issue, and while the former points to adaptivity of interaction within different phases of interaction, the latter points to content that reflects the immediate environment of the display, including the static location as well as dynamic events taking place in the vicinity. What is notable in the listing of Kuikkaniemi *et al.* is the strong presence of non-functional aspects. This suggests that design of interactive public displays must cover aspects of social contexts right from the ground up, and that it is crucial to analyze social contexts when reporting deployments.

Dourish (2006a) has presented a dualism between the physical, spatial features of a *space*, and the social conventions that people attach to a specific space, referred to as *place*. The coining used by Dourish is as follows: *"The space is the opportunity; place is the understood reality"*. This dualism of a potential deployment location should be taken into account by designers of interactive public displays. Akpan *et al.* (2013) empirically investigated this dualism through a deployment of an interactive public display prototype to different locations and evaluating how both space and place affect the willingness to interact. They effectively validate Dourish's definition by arriving to an empirical conclusion that "*while spatial factors had a significant effect on people's understanding of the interactivity of the installation, their understanding of the place had more influence on whether they actually interacted with it"*. The most successful places identified by Akpan *et al.* where those where the social context provided a 'license to play', i.e. where people can feel safe in framing themselves as actors within an interactive installation. Similar findings on the effect of location to the interaction activity were also discovered with the UBI-hotspots (Ojala *et al.*, 2012). The feelings of safeness and confidence correlate with levels of anonymity and association to a community, so that for example a strong association to a community brings feelings of safeness and confidence within that community. In public urban spaces, however, high level of anonymity is considered a social norm, and for example Ylipulli and Suopajärvi (2013) base their discovery of partially inhibitive practices regarding interactive public displays on the respect of this acknowledged norm. In public spaces with strong levels of anonymity, public interaction is generally considered inhibitive, whereas in more communal places with an existing 'license to play', public interaction is more acceptable and sometimes even desired. According to Akpan *et al.* (2013), *"more attention should be paid to understanding the different ways in which participants perceive the social context in which an interactive display will be placed"*. They suggest using dedicated people called *comperes* to initiate and sustain interactions, but also point out that *"it is difficult to work against existing social constraints, irrespective of the facilitation of spatial factors"*.

Impact on the engagement process

In case of interactive public displays, the viewing experience from layer one of the design space is complemented with a possibility to interact. This brings out a need to design ways

- to invite and motivate interaction,
- to implement the interactive functionality,
- to model the transitioning of viewers to active participants of interaction, and
- to balance the display usage among participants.

For the discovery phase of the engagement process, this means that besides perceiving the display artefact itself, citizens also need to discover the interactive features of the display. Similarly, the sense-making phase now includes the issue of learning how to interact with the display besides merely reasoning about the content. Through discussion of the literature, this section has shown how *vicarious learning* allows citizens to both perceive the interactivity, as well as make sense of the interactive features in a facilitated fashion.

Finally, the interaction phase is now part of the engagement process. The presence of interaction brings out a need to arbitrate the use of the display between citizens, and in this dissertation, a division is made between arbitration based on social conventions and arbitration facilitated by the display artefact. Examples of arbitrations based on social conventions include for example leveraging citizens collective understanding of territoriality (Azad *et al.*, 2012; Peltonen *et al.*, 2008). When discussing the next layer of the design space, the need for facilitated arbitration on behalf of the display artefact will be illustrated, and in Chapter 3 a case study which implements one type of arbitration solution on the level of each interactive public display will be discussed.

2.6.3 Layer 3: Multipurpose public displays

Multipurpose public displays represent the highest layer in the design space of this dissertation, which means that they inherit all the features from both of the lower levels, as well as add a host of new challenges. To separate MPDs from the two other classes of public displays discussed in previous sub-chapters, the definition given by Ojala *et al.* (2012) is adopted for this dissertation as follows:

"Moving from single-application displays to multipurpose [displays] creates new possibilities for display design. Although the line between single-purpose and

multipurpose display can be fuzzy, one distinction is the number of functions. Arguably, a display with multiple information types about a city is a single-purpose display because it has one function – to supply information. In contrast, a multipurpose display provides additional functions, such as browsing, games, galleries, and polls. Thus, functionality, not information type, defines the display."

MPDs typically balance between two main functionalities: digital signage, including advertising, and a set of value-adding applications. This duality inherently raises questions on how these functionalities should be balanced (Lindén *et al.*, 2010), and how the lifecycle of each application is managed, including development, distribution, provisioning and prioritization (Kostakos *et al.*, 2013). This also means that new stakeholders such as third party application developers enter the public display ecosystem. As an example, Hosio *et al.* (2014) assert that the location managers should be given increased control over the MPDs deployed in their premises, especially in terms of customizing the MPDs based on available applications. As this dissertation is mainly concerned with engagement of MPDs, meaning the relationship between the display artefact and the citizens, the author refrains from discussing the ecosystem of stakeholders further and instead refers the reader to other works that deal with this emerging ecosystem in detail (Alt *et al.*, 2012; Davies *et al.*, 2012; Ojala *et al.*, 2012).

Ojala *et al.* also give a tentative list of research questions related MPDs as an urban computing artefact, re-iterated below:

- What is the best way to present multiple applications to users?
- How can we exploit the competition among applications for user attention?
- How many applications should a display have?
- Should displays present one identical application grouping to all users, or should they adapt and customize their menu structure?
- Should users be able to install their own applications on the displays?

All of the questions deal with application management, where a single application embodies a certain kind of functionality. This is the key element separating MPDs from single-function interactive public displays. Challenges lie in how to enable effective application browsing within what are arguably short interaction times (Hosio *et al.*, 2013), and which stakeholders should have agency in application management across different locations (Clinch *et al.*, 2012). Through this dissertation, it is asserted that besides diversity in functionality, MPDs will embody diversity in ways they are engaged in practice, and especially that the so-called *deterministic use* of MPDs can emerge to indicate deeper integration of MPDs into sociocultural practice. When discussing deterministic use, it is important to separate between *intrinsic* and *extrinsic* motivation. Furthermore, it is important to note that most interactive public display designs rely on extrinsic motivation mechanisms to opportunistically invite passers-by to interacting with the display.

When defined this way, MPDs are established as a highly flexible platform for various application use cases, some of which surpass the notion of 'opportunistic, ephemeral use'. Gonçalves *et al.* (2013), for example, have investigated framing interactive public displays as tools for situated crowdsourcing efforts. These new functional framings embodied by the concept of MPD highlight the fact that besides only balancing between digital signage and value-adding applications, MPDs also need tools for balancing between opportunistic and deterministic use. It can also be argued that if MPDs afford engaging user experiences leading to appropriation and increased adoption, deterministic use can account for a significant fraction of overall use. This projection bears similarities with Sellen *et al.* (2009) in *"how the use of technologies may unfold over time and in different situations"*.

Impact on the engagement process

Compared to layer two of the design space, MPDs complement interactivity with the balancing of multiple use cases, as well as balancing opportunistic use with deterministic use. While deterministic use can take place also with single-purpose interactive public displays, it is more logical to place it on the third layer of the design space. As an example, one of the design principles given by Vogel and Balakrishnan (2004) refers to *short-duration fluid interaction*, which may not be the case within the deterministic usage model.

Another issue that requires emphasis in MPDs is that for deterministic use, discovery of a display needs to be supplemented with the notion of discovering the needed functionality, and this supplemented discovery is referred to in this dissertation as *mapping*. Mapping combines steps of discovering a display, discovering its interactivity, as well as discovering a desired functionality, and can thus facilitate the overall engagement process with the MPD. To enable this, and thus to facilitate the execution of all discovery steps, solutions are needed that better integrate these individual steps and allow citizens to make informed decisions on where to find displays with needed capability and suitable availability. In other words, through mapping solutions citizens can move from peripheral awareness to informed awareness regarding public displays.

Finally, MPDs require arbitration functionality that complements the traditional reliance on social conventions. The reason is that as functionality of a public display gets more diverse, traditional models on sustained interactions based on vicarious learning may not hold, and there can be discontinuities from usage of one application with one interaction modality to another application with potentially different interaction modality. For this reason, engagement of an MPD should be seen as an *interaction session* during which one or several applications are being used, and the utilization of an MPD is thus a sequential collection of these application sessions, with stochastic idle times in between. In the face of this model, possible arbitration solutions should seek to leverage the notion of this interaction session for managing the overall utilization of the MPD, both within a single session as well as between consecutive sessions.

2.6.4 Synthesis

Throughout sections 2.5 and 2.6, the author has illustrated how public displays have first emerged to urban spaces in a large scale driven by digital signage, and how commercial systems and academic prototyping have now entered a synergistic cycle where presence of commercial public displays first sparks interest in academia, and new concepts and solutions from academia represent potential future steps for commercial systems. Although majority of commercial digital signage systems are still passive, interactive solutions are gaining traction in making public displays and their content more immersive[4].

Against this development, the MPD concept represents a potentially disruptive evolution, especially due to its malleability in terms of diverse functionalities. It is this malleability for diverse use cases that allows MPDs to be framed as urban computing tools, through an associated design space. This again allows MPDs to be adopted as a tool for various urban sociocultural practices, which again can change how interactive public displays are perceived and

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[4] See for example http://www.magicmirror.me, or http://www.shikumi.co.jp.

utilized, eventually giving rise to new mental models that re-conceptualize the entire notion of what a public display is and what can be done with it.

Figure 7 illustrates the overall design space for public displays discussed throughout this chapter. While the individual insights of the design space come from related work as well as from the author's own research, this design space is the first one to the author's knowledge to aggregate this knowledge into an integrated representation that facilitates reasoning on different design alternatives. As can be seen, besides being subject to the traits of the lower layers of the design space, MPDs introduce as new design challenges the management of applications, stakeholders and usage models. Mirroring this overall design space to the earlier definition of engagement as a qualitative list of traits (section 2.3) attached to a user experience with a technology, it can be seen that most of the traits are already fulfilled within the layer of interactive public displays. However, novelty as a trait tends to wear off when awareness of the new technology prolongs. To maintain motivation and interest and develop affect towards MDPs, use cases that offer meaningful sociocultural practice need to evolve. The following chapter presents and discusses a collection of case studies within this design space that highlight human-computer interaction solutions in the face of this hypothesized deterministic usage.

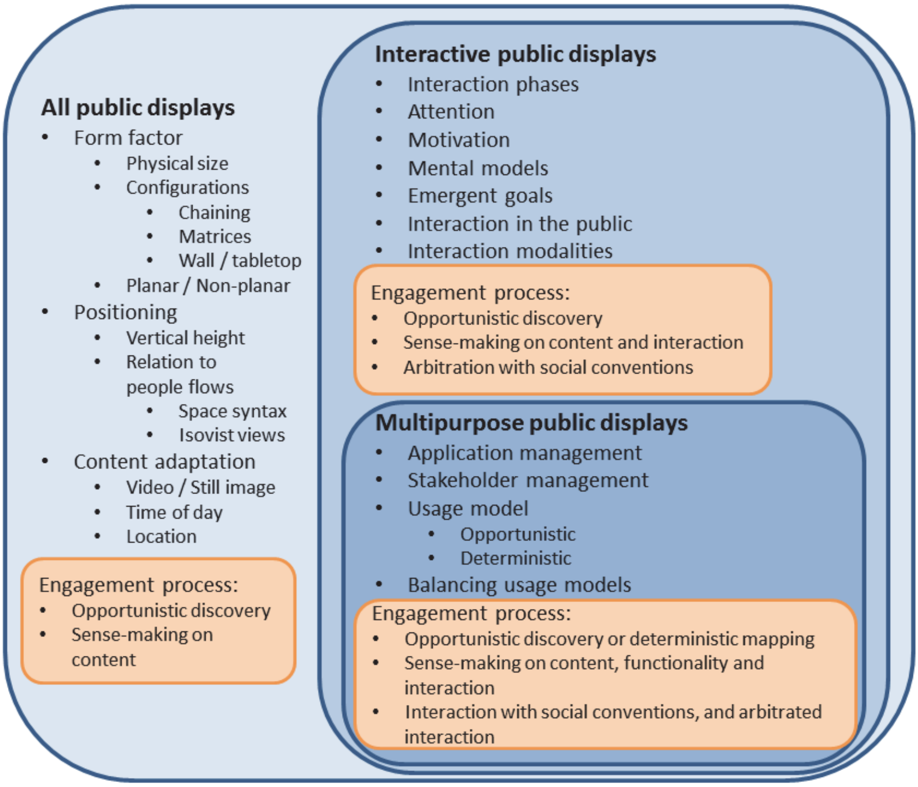

Fig. 7. Design space of public displays, arranged in layers according to different conceptualizations. The steps of the engagement process are also listed on each layer.

3 Case studies

The empirical research carried out for this dissertation is arranged into three separate case studies that all constructively explore the design space and the engagement process formulated in the earlier chapters. For each use case, a general motivation and overview is presented, followed by discussion of the main insights, as well as how they contribute to the theoretical formulations. Finally, a synthesis of all the use cases is given prior to the overall discussion of the dissertation.

3.1 Case study 1: Personal cursors for public displays

The case study reported in Publication II (PII) empirically investigated one possible solution to the interaction phase of the engagement process for interactive public displays based on mobile input. The case study was motivated by urban public displays where interaction by touch can be problematic due to various obstacles, for example shop windows or other obstructions such as metro tracks (Boring *et al.*, 2009). Adhering to principles presented by Rashid *et al.* (2012), the mobile device was cast as the main input device, while the public display acted as the sole visual output device.

To enable a generic set of interactions and thus to generalize across several application domains of public displays, a cursor-based control of public displays was chosen, and a decision was made to comparatively evaluate three interaction techniques for their specific strengths and weaknesses. Cursor-based solutions for external display systems have also been suggested in the so-called multi-display environments (MDE), where a personal workspace is divided into multiple displays. Xiao *et al.* (2011), for example, discuss a concept called *Ubiquitous Cursor*, which allows users to get real-time feedback on the location of the cursor within the MDE.

For the experiment, Nokia N96 models were used as mobile devices. They feature four directional keys with a joystick button in the middle, a camera for optical flow analysis, as well as acceleration sensor for detecting the tilting angles of the device from a programmed zero point. This setting allows mobile input to cover three of the basic operations of WIMP (windows, icons, menus, pointers) user interfaces, namely select, hover and drag. The techniques compared are concisely presented next.

Scroll is the simplest controlling technique, where the directional keys (in case of smartphones with physical joysticks, such as the Nokia N96) are mapped directly to cursor movement with a control-display (CD) ratio[5] of one. This presents a slow but steady technique for controlling a cursor on a public display. *Tilt* maps the cursor speed to the tilting angle of the mobile device from a programmed zero point, which was set to the angle when reading content from the mobile device's screen while standing. This setting behaves in a fashion similar to a two-dimensional isometric joystick, with a changing CD ratio based on the tilting angle. The benefit in this approach is that the cursor speed can be adjusted on a large range, but precise operations with the cursor can become tedious.

Finally, *move* utilizes the mobile device's camera together with real-time optical flow analysis in order to simulate mouse movements with the exception of not requiring any surface for the device to rest on. As move also exhibits a CD ratio of one, it was decided to combine moving the device together with a tilting angle, so that tilting angle determines the CD ratio and movement of the device determines the direction the cursor will move to with the current CD ratio. See Figure 8 for illustrations of these interaction techniques.

Evaluations were carried out in a laboratory environment, with test participants carrying out target acquisition tasks with each of the techniques. The primary tasks presented to users in the evaluation of these techniques were target acquisitions with varying target sizes and distances. Although the interaction techniques are in principle application-agnostic, a target selection on a large map rendered on the public display was simulated in order to increase ecological validity of the experiment. A 50-inch display panel was placed on an average eye-level so that users were positioned approximately 1.5 meters away from the display during the interaction. Twelve participants participated in the evaluations. Further details of the evaluation can be found in PII.

During the evaluation, the participants also expressed subjective ratings for the techniques compared. Scroll was perceived as the easiest and most accurate method, although it performs worst in terms of selection time. When subjective ratings were gauged in terms of operation speed, however, move and tilt were consistently rated higher. In terms of general comfort, no significant differences were expressed across the techniques. Several participants stated that the non-

[5] Control-display ratio is a normalized scalar that represents the ratio between change in control and change in display (or alternatively outcome, or response).

constant techniques of tilt and move/tilt, i.e. techniques with dynamic CD-ratio, introduce a higher skill requirement and would thus be suitable for gaming scenarios.

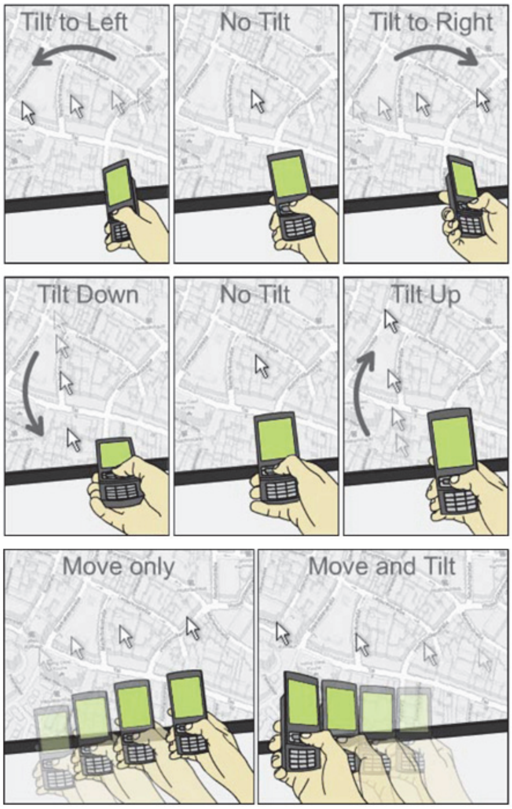

Fig. 8. Illustrations of tilt and move interaction techniques. Copyright ACM Press, 2009, Publication II.

Considering the qualitative traits of engaging user experiences (section 2.3), this study provides several insights: first, the learning curve exhibited by the tilt mechanism could be utilized as a challenge in game or gamified scenarios on interactive public display to increase engagement. Additionally, the fast feedback of cursor control presents a clearly perceived control. As a practical limitation, the feedback loop itself is very sensitive to network errors or lag. The other techniques besides tilt are applicable to scenarios where the overshooting effect, i.e. the movement of the cursor over the target, is more severe.

Whereas the move technique features increased physical exertion for the arm and is thus less discrete in terms of interacting in a public context (Kuikkaniemi *et al.*, 2011), tilt technique can be maintained discrete while allowing flexible movement in terms of cursor speed. Similarities can also be found to the findings of Kurdyukova *et al.* (2012) in that mobile gaming scenarios implemented through the tilt mechanism would allow people to freely situate themselves within the nimbus of the public display, allowing flexible spatial organizations for example for collaborative gaming scenarios. Since the spatial organization is loose, new players could easily join in with their mobile devices, hinting towards open-ended games where participants can enter and leave the game on-demand. In case the game is collaborative, playing against other players can maintain a challenge even when novelty from the interaction technique itself has faded out.

This case study situates on layer two of the design space, meaning that it is applicable also to MPDs on layer three. Within the engagement process, discovery and sense-making were omitted for investigating interaction-related aspects only. Arbitration on display access was also omitted due to controlled execution of evaluation tasks. The case study was conducted in laboratory conditions with a quantitative evaluation complemented with subjective ratings, meaning that aspects of real-world context were not assessed.

3.2 Case study 2: Context-aware leasing

The case study reported in Publications PI, PIII and PIV investigates the modeling of interaction sessions discussed earlier in section 2.6.3 through a solution based on *context-aware leases* that can be requested by citizens from MPDs. As alluded earlier, this modeling can then be leveraged both in implementing deterministic mapping functionality, as well as in arbitrating access to an MPD. The functionality presented in Publications PI, PIII and PIV was motivated by the following argumentation related to deterministic use of MPDs when utilized in conjunction with mobile devices (PIV):

"Device pairing, however, is only intended for joining two devices together as a logical whole. We argue that [public] display utilization based solely on pairing can become a bottleneck when the amount of displays grows, as besides current social conventions of queuing and polling, users have no way of inferring the status information of a certain target display. In addition, there might be

available displays close-by, but if they are not in line-of-sight, users cannot discover them."

This argumentation closely follows the discussion in section 2.6.3 regarding the need for new solutions to facilitate discovery of MPDs, as well as to leverage the notion of interaction sessions. For the discovery phase, the problem is in integration of location, functionality and availability information, and for the interaction phase, the problem is in modeling interactions as sessions in order to allow arbitration on behalf of the MPD itself and thus facilitate deterministic use. When comparing these problem settings, it is evident that while modeling an interaction session within the MPD and managing these sessions can aid in the arbitration of interaction, this modeling can also establish a rudimentary metric for the availability of an MPD and thus aid in the mapping of displays in the discovery phase.

This case study proposes the notion of a *lease* as a basis for which interaction sessions can be modeled and managed. To model interaction sessions as leases means that citizens should be able to negotiate for a lease to a certain MDP of their choice, and during the validity of that lease, engage the MPD for interactions. This case study illustrates how the benefits of this notion have been leveraged in both the discovery as well as in the interaction phase of the engagement process.

PI presents a design and implementation of a mapping client for the purpose of deterministically discovering a suitable public display for engagement. Its functionality is based on aggregating the availability information from each MPD nearby the citizen through a publish/subscribe network, and then presenting this information in an integrated fashion. When implemented in this way, citizens can be informed on the locations and dynamic availabilities of each MPD, instead of having to rely on opportunistic discovery.

The mapping client, called *ScreenSpot*, takes two notions of target MPDs as the basis for its representation: The distance of each MPD from a citizen's current location, and the temporal availability of each MPD in terms of currently active leases set by other citizens. Based on these two criteria, a radar-style visualization display is presented to the citizen, populated with candidate MPDs. In this radar view, each ring represents a discrete level of distance from the citizen, while temporal availability acts as a radial parameter, situating each MPD within its ring to a specific angle from the zero-point, denoted in the design as the twelve-o'clock of a clock face.

Figure 9 illustrates the functionality of the ScreenSpot mapping client. After issuing a query to the network of MPDs, the client presents the integrated view of results (upper left screenshot). The selected MPD in the screenshot is located on the second ring of the radar view, and since its location on this ring deviates from the zero-point, it means that it currently has at least one active lease set by another citizen and is thus not immediately available for interaction. To indicate more precise temporal availability, the tooltip of the selected MPD is showing that the active lease is still valid for two minutes and sixteen seconds.

In case the citizen wants to know further information regarding the actively selected MPD, pressing ‘More’ will bring out an information view that can present more detailed information of the display. In this case, the additional information consists of a symbolic location (‘Cafeteria’) together with the maximum supported resolution. When the citizen chooses one of the candidate displays from either the radar view or from the information view, a lease for that MPD is automatically placed on behalf of the citizen.

Considering the requirements listed for discovery of MPDs in section 2.6.3, it can be seen that the ScreenSpot prototype addresses two of the three criteria: location and availability. This means that issues related to desired functionality are not included in this prototype, and remain a challenge for future work. Another issue with this prototype is that it does not account for any opportunistic use taking place with a candidate MPD, as it only accounts for leases placed through the mapping client. It is thus a challenge for future research to meaningfully balance between usage that emerges from opportunistic discoveries of interactive public displays, as described in section 2.6.2, and deterministic use initiated through a mapping client such as ScreenSpot.

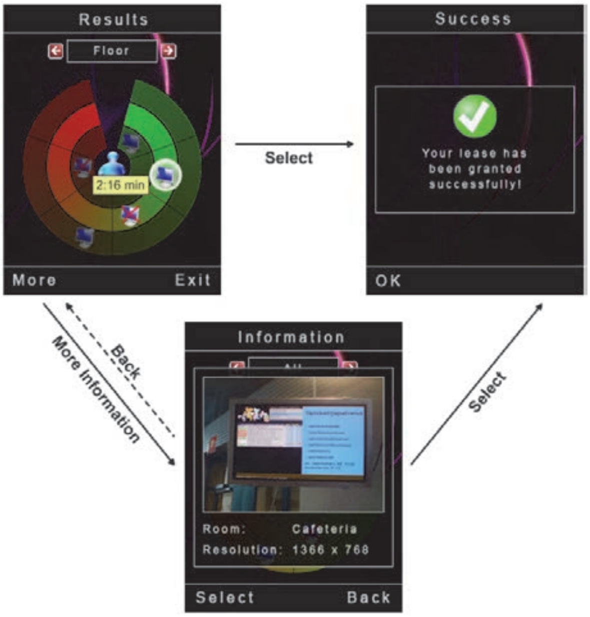

Fig. 9. Example screenshots of the ScreenSpot mapping client. Copyright ICST, 2008, Publication I.

PIII and PIV report an in-the-wild evaluation of the same leasing concept acting as an arbitration mechanism for MPDs. Whereas in ScreenSpot's case the prototype functionality was primarily on the mobile client side with simulated candidate MPDs, in this prototype, both the mobile client and the MPDs were designed and implemented with middleware functionality that allowed leases to be placed and example applications to be executed on top of an active lease. PIII focuses on the design and implementation of the mobile client, while PIV focuses on the design and implementation of the leasing functionality on each MPD. This prototype was not coupled with any mapping client, but instead allowed citizens to place leases on MPDs in-situ via a combination of an RFID reader unit on each MPD and an RFID tag accessory attached on the mobile device. Figure 10 illustrates concept designs of this mobile device accessory, whereas Figure 11 illustrates the wider software architecture in the case of the UBI-hotspots.

Fig. 10. Concept designs of an RFID accessory for leasing MPDs. Copyright Springer, 2011, Publication IV.

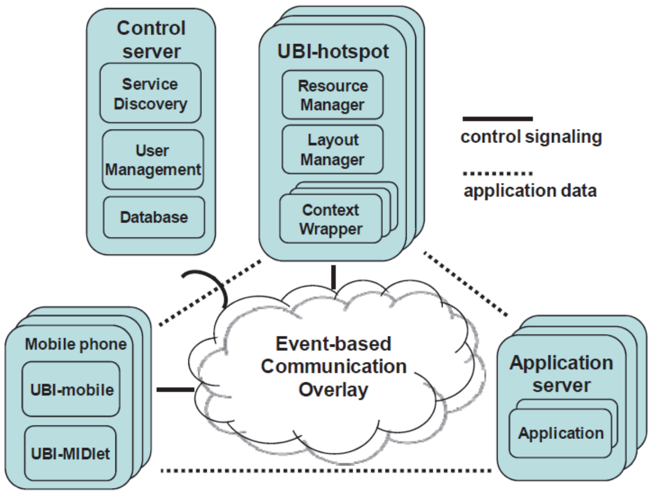

Fig. 11. Software architecture of the UBI-hostspots. Resource manager component on each hotspot is responsible for communicating availability information for mapping clients, and for managing leases requested by citizens. Copyright IEEE, 2010.

The prototype functionality was as follows: the citizen initiates a leasing of an MPD by touching the associated reader with the accessory. Based on the configuration of existing leases on the MPD, the citizen is either granted a private lease to be either active or pending, granted a social lease, or joined as part of an existing social lease. The type of lease required is inferred from application metadata, and for example multiplayer games required social leases. If the lease is new, i.e. no existing lease was joined, the citizen will choose an application from the mobile device to be executed on the MPD. In the case of joining an existing lease, the citizen can only launch the application currently being used on the MPD. A lease is terminated when the last active participant of that lease terminates it. In this case, a citizen with a pending lease to the MPD will get a notification of his/her lease becoming active at the MPD. Further details can be found from PIII and PIV.

As PIV is mostly a middleware-focused paper, it reports a performance evaluation regarding the signaling traffic between a mobile client and an MPD. More interestingly for this dissertation, PIV also includes interview data that uncovers citizens' attitudes towards this prototype functionality in-the-wild. The following interview excerpts have been extracted from PIV:

"I'd use them (services to mobile) if they are made easy enough. If too many steps are involved, I'm not going to bother." (Male, 19)

"I doubt that I would use this [functionality]; I'm not accustomed to use my mobile device that way." (Female, 25)

"I mostly use my mobile device for calls and SMS. But if this functionality would generalize and be simple to use, I might consider it." (Female, 26)

These interview excerpts indicate that mental models related to both mobile devices as well as public displays tend to constrain the expectations people have towards these devices. The last excerpt indicates cautious support for the functionality, again constrained by the prevailing norms in public urban spaces.

Considering the design principles discussed in section 2.6.2, functionalities like on-demand leasing of MPDs clearly represent a disruptive viewpoint towards how interactive public displays can be used, and this is also reflected in citizen assessments of the functionality. Compared to emergent and playful interactions, systems like on-demand leasing clearly bring a new viewpoint into discussion: MPDs can also be used beyond lightweight and temporally short interactions, and in order to better chart their potential, MPDs should be experimented as a flexible platform for supporting urban sociocultural practice.

Considering the limitations of PI, PIII and PIV, one obvious shortcoming is that the engagement process of MPDs consisting of mapping, sense-making and arbitrated interaction was not evaluated as a whole. Instead, PI gives insights into mapping, while PIII and PIV report findings on the arbitration. The sense-making as a phase of the engagement is also problematic, because it inherently exists as part of the process, but it is challenging to isolate into investigation in any clean means, as it always manifests as part of the other phases associated with the engagement. What can however be said of the sense-making in terms of the publications reported in this case study, is that it is not yet at the level where citizens are willing to go through setup procedures to establish usage sessions on MPDs. As mental models for MPDs are currently lacking, sense-making as a process has no solid ground to build on, leading to potential confusion regarding the purpose of MPDs.

3.3 Case study 3: Proxemics and multimodality

The case study presented in Publication V (PV) considers an arbitration solution based not on explicitly requested sessions as in the case of context-aware leases, but instead on implicit arbitration based on physical presence and orientation. The modeling of presence and orientation were built on the principles of proxemics interactions (Greenberg *et al.*, 2011). The development was motivated by a perceived need for MPDs to better recognize presence and especially attention of citizens in front of the MPD, and base the inviting and motivation of interaction on implicit input. The prototype was brainstormed based on the concept of MPD, and was subjected to a two-day field trial as part of an open science exhibition.

The prototype, called FluiD for 'fluid display', was designed to accommodate digital signage as well as two interactive applications, and the interactions were designed on a combination of a Microsoft Kinect controller and a multi-touch panel. The interactive applications were a 'jackpot' application that resulted in a localized advert, as well as a map centered on the location of the display. The inviting of interaction based on physical presence and attention, and the launching of the applications based on mid-air gesturing were implemented through the Kinect controller. The interactions with the applications however were intentionally designed to leverage an interaction modality other than those used to initiate the interactions with the display. With this design, we wanted to explore citizens' willingness to switch interaction modalities during the interactions. The localized advert application encouraged mobile interaction with an attached QR code for picking up a discount coupon from the shown ad, while the map was made to be used through the multi-touch panel.

Figure 12 shows the phases of interaction designed into the FluiD prototype. In idle mode, the display is showing digital signage. When the Kinect sensor detects presence of people (blue circles with arrows denoting focal attention) in front of the display, two application previews roll out from the sides of the display. When focal attention is detected, the application previews are augmented with cues for mid-air gesturing, inviting interactions. Applications could be launched with two sweeping gestures towards the center of the display: right sweep with a left hand (left application) or left sweep with a right hand (right application).

Detecting a presence can be done with a Kinect sensor directly, while the focal attention was deduced by detecting a face and associating it with one of the detected persons. In order to successfully launch an application, a person was required to be in front of the display (presence), look towards the display (focal attention) and perform the correct mid-air gesture (a correct sweep with either hand). After a successful sweep, the associated application would launch and fill the screen, followed by interactions with that application. Interactions were terminated by walking away from the front of the display, and after a short time, the display reverted back to the digital signage mode.

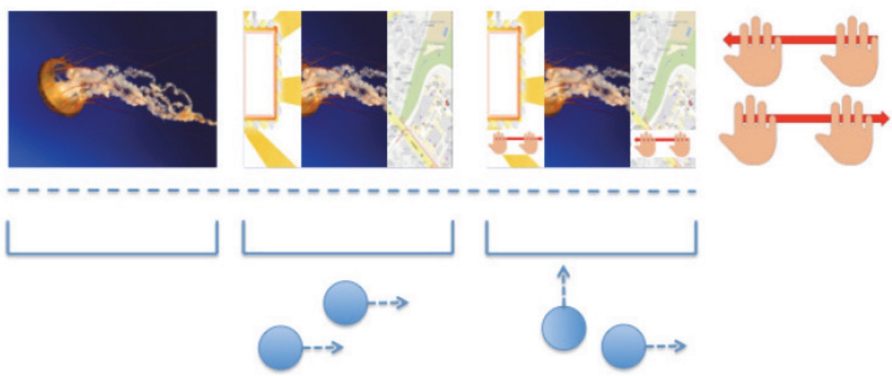

Fig. 12. Interaction phases of the FluiD prototype. The rightmost image shows a close-up of the gesturing cues. Copyright ACM Press, 2013, Publication V.

Data collection from the two-day field trial was done through on-site observations of interactions with the display, coupled with the participants filling out a short questionnaire after the engagement for gathering Likert-type data. Researchers were on-site at all times, discussing the prototype with fair visitors and encouraging visitors to try out the prototype. When dealing with new visitors, researchers never revealed the interactive features directly, but instead allowed the visitors to explore the interactivity.

In terms of the engagement process, the designed prototype supported opportunistic discovery, but the access to the interactive features was arbitrated by the Kinect sensor. Only participants within the sensor's field of view with the correct orientation could give input to the display. The size of the area visible for the sensor, coupled with the nimbus of the interacting participant (Ten Koppel *et al.*, 2012), tended to create an interaction area fit for one participant at a time. This was further emphasized by the performative nature of the mid-air gestures, acting as an indicator for others to keep a respectful distance. This prototype design is an example of how interaction modalities can be leveraged in design to scaffold the social context in front of the display and alleviate the ambiguity related to the interaction space, as highlighted by Greenberg *et al.* (2014).

The results regarding the interactions and the multimodality were quite clear: participants had difficulties in assessing the correct trajectories and magnitude of the mid-air gestures based on the cues alone, and were very reluctant to switch interaction modalities during the interactions with the applications. The difficulties in assessing the correct gestures is in line with Norman's (2010) discussion on gesture interpretation. After launching the map application, participants attempted to pan through smaller versions of the application launching mid-air gestures, which was clearly the result of the sense-making related to the interaction: because the display takes input from mid-air gestures in the beginning, it is reasonable to assume that it continues to do so. By provoking modality switches through design, and observing the persistence within one modality in practice, it was uncovered that designers need to carefully weigh whether interactions require modality changes, and if so, these changes need to be communicated very clearly. As participants attempted mid-air gestures to the map, the unresponsiveness was almost always accounted to incorrectly performed gesturing, i.e. participants quickly assumed personal fault in a case where the original design did not match the sense-making and interactions that manifested in practice.

3.4 Synthesis

The case studies presented in this chapter illustrate several of the aspects raised in Chapter 2. Concerning the design space, one case study situates on layer two (which means it is applicable on layer three as well), whereas two case studies situate on layer three. The sense-making was the only part of the engagement process not explicitly evaluated, but as alluded in section 3.2, it is difficult to isolate it in terms of investigation. In terms of methodology, the case studies feature laboratory evaluations, a semi-controlled field trial, as well as an unsupervised in-the-wild evaluation. Through the case studies, it becomes evident that laboratory evaluations provide clean data from instructed use, while in-the-wild evaluations provide heavily confounded data which is however maximized in terms of ecological validity. In the middle, is the field trial, where scaffolding from researchers can help in building rapport with participants and thus gaining more complete data, while at the same time requiring reflexivity in acknowledging the research presence in the data gathering process (Johnson *et al.*, 2012).

Overall, the case studies and their findings situate to the presented theoretical framework as follows: case study one examines the interaction phase of the engagement process on levels two and three of the design space. Through laboratory evaluation, the input techniques based on non-linear CD ratios were seen as viable candidates for gaming scenarios. Especially the aspects of *challenge* related to engaging user experiences can be implemented with these techniques. Case study two focuses on all steps of the engagement process on level three of the design space. Here, an in-the-wild evaluation highlighted important non-functional aspects of a prototype that was earlier functionally validated in laboratory conditions. Especially the mental models were seen as inhibiting larger scale use, although the interview excerpts indicate cautious optimism on behalf of citizens. This indicates that future designs need to leverage existing mental models and context-specific behavioral patterns more carefully. Finally, case study three focused on the sense-making and interaction phases of the engagement process on layer three of the design space. When using proxemics to heuristically inform design of MPDs, issues related to implicit input are emphasized. By provoking modality changes in interactions, it was shown that multimodal interactions need to be strongly justified and clearly communicated, and that otherwise citizens tend to stick to one modality. This case study also validated parts of the dark patterns in proxemics discussed by Greenberg *et al.* (2014), especially the potential difficulty of opt-out from interactions, and the ambiguities related to the use of physical space.

Even though the case studies only investigate aspects related to public displays and citizens and thus omits other stakeholders, as stated in section 1.3, it is still evident that the interaction settings alone are very complex in nature.

Issues of motivation and dynamics of social context impact the interaction context at all times, and people's backgrounds affect how they reason and make sense of the prototypes. From a purely positivist perspective, these settings appear as confounding, but as illustrated in section 2.4, HCI as a larger field is moving towards more realistic evaluation environments and thus must find tools and theories in order to facilitate understanding technology use in real-world contexts over longer periods of time.

4 Discussion

This chapter discusses the research conducted in this dissertation as a whole, through the original research question and objectives, through the contributions, and through comparison to related work.

4.1 Research question and objectives

This dissertation set out to address the following research question:

How can multipurpose public displays facilitate the engagement process in order to establish MPDs as an everyday artefact of smart urban spaces?

This research question was then divided into two objectives as follows:

The first objective is to extend the current design space of interactive multipurpose public displays with the proposed three-phase engagement process, as well as with the functionalities of mapping and arbitration.

The second objective is to constructively investigate how the three phases of the proposed engagement model are affected by the functionalities of mapping and arbitration.

The construction of the design space is framed as a contribution, as it draws together isolated findings from several parts of related work, and presents a body of findings as one integrated representation. To extend the design space, the phases of the engagement process on focus were situated on each layer, allowing designers of public displays to see which phases of engagement need attention. The layered structure of the design space also helps in seeing how features from lower layers are inherited to the upper layers, thus increasing the complexity of design.

Construction of the design space set out mostly from the focus of how related work had modelled interactive public displays, meaning that originally the design space only had one layer. The layered approach was, however, adopted when the author discovered that some of the aspects affecting design apply equally to both interactive and passive public displays. This meant that some features like those affecting the visibility could be placed on a lower layer, and be inherited to all solutions featuring interactive public displays. The MPD concept based on the integration of multiple functionalities on a single hardware platform gave rise to a third layer. Unlike related work which shows design spaces on single layers, the design space presented in this dissertation aggregates aspects on multiple layers.

The engagement process presented in this dissertation has also been influenced by models from related work, discussed in section 2.6.2. What separates this model from related work, however, is the inclusion of the mapping and arbitration functionalities, and in general promoting the deterministic usage model as a complementary way of engaging MPDs in urban spaces. Through discussion of technology adoption that goes beyond playful interactions motivated largely by curiosity, the deterministic usage model envisions a significantly different role for interactive public displays in urban spaces, one that ultimately seeks to redefine how public displays are perceived and understood. This new perception and understanding is then intimately tied to the sense-making phase of the engagement, and requires new mental models to emerge.

Finally, the case studies presented naturally represent the author's own contribution. While some of the experimentation such as PI and PII focus on a single phase of the engagement process, others such as PIII, PIV and PV give insights into how the design decisions made on prototypes impact multiple phases of the engagement process. The case studies also highlight the difficulty in optimizing a certain set of features in a design, and should be seen more as investigations that begin to uncover the boundary conditions that citizens perceive as important in practice, and that are most suitable for citizens and for different contexts. The case studies were originally conducted as separate from the presented design space, but since they all shared certain themes, they represent a good fit for demonstrating how different aspects of the design space can operationalize in practice.

When comparing the case studies to those reported in related work, certain key differences can be drawn. Vogel and Balakrishnan (2004) have in their design principles advocated for ephemeral interactions without explicit sing-in or sign-out activities involved. This principle is fundamentally re-thought through the notion of deterministic use on the third layer of the design space, and especially the leasing functionality allows citizens to engage MDPs beyond ephemeral interactions. The principle of vicarious learning presented by Brignull and Rogers (2003) continues to be relevant, but it may not have the same effect in the case of the MPD. As MPD is defined through applications that each may embody certain principles of interaction, vicarious learning may only benefit the learning of that single application, without revealing the actual multipurpose nature of the MPD to the bystanders.

An additional aspect is the relation of the display's physical size to its feasibility for leasing. Displays adhering to the size of normal desktop monitors, and functioning as information kiosks, ATMs or airport self-service stations, implicitly adhere for use by one person at a time, and the design of these stations allows bodily occlusion to create a temporary private interaction space. On the other end of the spectrum, large wall displays and even media facades feature very high visibility, meaning that regardless of interacting, a significant audience can be expected to observe the overall screen real-estate. In these settings, leasing represents a possibly unwanted 'hijacking' of the public screen.

It seems that the most feasible form factor for the leasing functionality in terms of physical size is a display that can comfortably accommodate 1-5 simultaneous persons. Here, the physical presence of a small group can clearly indicate to others that the display is being actively engaged at the moment, while still allowing social use within the group members. This discussion on the relationship between arbitrated interactions and physical size of the screen real-estate again demonstrate how aspects from different layers of the design space come together to form a basis for new research questions. This forming of new questions is also the crucial step for starting to formulate a new theoretical basis to *"better explain the interdependencies between design, technology and appropriation"* (Rogers, 2011).

Finally, as an answer to the original research question, it can be stated that MPDs as urban computing artefacts offer a multitude of possibilities for facilitating the engagement process, and that this facilitation is more efficient the better it is integrated to existing and commonly accepted mental models and sociocultural practices. Leasing can be seen as a solution leveraging the notion of explicit reservations and notifications to reservations becoming active, akin to a queueing system based on running queuing numbers, whereas proxemics leverages the more natural understanding of a citizen's personal space. The challenge in future work lies especially in recognizing what kind of practices in what contexts offer the best leverage for design.

4.2 Methodology

Methodologically, this dissertation does not represent any single style of evaluation, but instead demonstrates different approaches in practice through the case studies. As the author's background is in computer science, it was natural to carry out the first evaluations (PI, PII) in controlled laboratory conditions. During the work within the UBI program, the possibility of conducting genuine in-the-wild research within the UBI infrastructure lead to the research described in PIII and PIV. In the case of PV, the methodology for the field trial was chosen to include researchers, since the prototype also acted as an exhibit that required attendance. This approach complemented the approaches of laboratory and in-the-wild conducted in earlier publications.

In-the-wild methods are seen as a necessary step to move new technology out from the research laboratories, and to perform longitudinal evaluations in real-world contexts. It should however also be remembered that in-the-wild evaluations still lack a solid theoretical basis, and the data gathered should be seen as forming a critical mass, from which emergent features can be drawn out with careful curation and processing. Especially the presence of a researcher is a double-edged sword, since researcher presence can potentially confound the user experience with a new technology, but on the other hand, the user experience might not take place without an encouragement from an on-site researcher who can help with engaging a prototype technology.

As an example of current challenges, in-the-wild methods cannot guide citizens, so this type of evaluation cannot guarantee that all the designed features of a system will be explored. This is in contrast to laboratory evaluations where a protocol for the evaluation specifically takes care of exhausting the feature space to receive data equally for the entire functionality of a prototype. Thus, recent papers have incorporated a method where a prototype is designed based on a set of heuristics, evaluated in a systematic fashion in laboratory environment, and finally subjected to a longitudinal in-the-wild evaluation (Müller *et al.*, 2012; Schmidt *et al.*, 2013). This method combines the best of both worlds according to current knowledge of the methodology, but in the future, the community will need to more systematically reflect on the epistemological underpinnings of different methods and their suitability in relation to each other. As an example, *design probes* (Gaver *et al.*, 1999; Wallace *et al.*, 2013) and *critical design* (Bardzell *et al.*, 2012) take a phenomenological approach in charting design challenges.

Ultimately, the scale of the evaluation should determine which methods will be used. This means that focused investigations into smaller portions of a new technology can be made in the laboratory, and after lab experiments have deemed these parts as validated, they can be aggregated and released to in-the-wild contexts. This in-the-wild context can then be supported in the beginning by on-site researchers in order to build rapport with a critical mass of users. After the technology is mature enough, and sufficient rapport has been built, an unsupervised in-the-wild evaluation in a maximal scale can take place. Naturally, this is an ideal progression.

A final aspect considering in-the-wild evaluations is the considerable impact of non-functional aspects into the overall user experience. The backgrounds of people were already briefly alluded to in section 3.3. However, such ubiquitous issues as weather in its different forms can have a major confounding effect unless it is properly accounted for in analysis. To pay special emphasis on weather in in-the-wild evaluations, especially on geographical areas with distinctive seasonal changes, Ylipulli *et al.* (2014) have suggested a framework for the so-called 'climate-sensitive urban computing'. Another example is the bureaucracy involved in organizing in-the-wild evaluations. Zarin *et al.* (2013) report the bureaucratic challenges that can arise between when a decision is made to deploy an interactive public display to a public urban space, and when it is actually deployed. These approaches are a signal that the urban computing research community is starting to embrace in-the-wild contexts in all their 'messiness' (Bell & Dourish, 2007).

4.3 Research history

This dissertation work started out as a vision-driven software engineering project: 'What kind of middleware support we will need, when all surfaces around us are digital and interactive, and when people engage them with various novel and even mundane activities', was the question posed to the author by his supervisor. Because the author's education and previous experience were strongly related to embedded software systems, the initial vision was to design *a middleware-level resource manager* for public digital surfaces in the user's environment, and to evaluate this manager in terms of system-level performance, including scalability and latencies, as for example reported by Gajos *et al.* (2002).

In retrospect, this vision represents a significantly different interaction paradigm than what people are comfortable with at the moment of this writing. This paradigm gap would later surface in the interview data gathered in the first in-the-wild evaluation. Interactive public displays are still a novel technology in urban spaces, and the associated usage process is rife with non-technical issues such as social pressure, social conventions, mental models (and the lack of them), weather and cost structures, to name only a few. Furthermore, the explicit setup procedures required by our context-aware leasing prototype led the author to think how in the future we could shift some of the setup to implicit interaction (Schmidt, 2000), and this in its turn led to the utilization of proxemics (Greenberg *et al.*, 2011) in the subsequent prototype.

Methodologically, dissertation research began with positivist-oriented laboratory-based work, where quantitative metrics such as task completion time and error rate were measured from informed test users, and statistical methods were utilized to generate design implications from the measured metrics in different test conditions. This view however changed during the first in-the-wild studies, as the complexity of the evaluation context in general grew exponentially. Suddenly, the presence of a multitude of confounding factors were present, data were by default more fuzzy than in laboratory conditions, and users were free to take paths in interaction not originally designed by researchers.

Despite these challenges, the data and experiences gathered from in-the-wild contexts were valued, since they represent genuine use conditions and maximal ecological validity. The author has also come to acknowledge a research process where a prototype is first tested in laboratory conditions prior to an in-the-wild deployment, and how the methodologies can drastically differ in these two phases. The question of how to combine in-the-wild evaluations and associated methodologies with lab-based quantitative evaluations is currently a topical discussion point within HCI and urban computing research communities.

5 Conlusions

The concepts of deterministic use, mapping and arbitration represent the view of how the author sees the utilization of interactive public displays shaping in urban spaces in the future. This means that most of the work presented in this dissertation is by definition based on informed scenarios of the future. To bring validity to this method of research, the quote of Bardzell and Bardzell (2014) is re-iterated as follows:

”In arguing for the reinvigorating of the [ubiquitous computing] vision agenda, we believe that the research community will need to engage in a serious and sustained way, as Weiser did, in cognitive speculation about (a) what technologies and lived environments might characterize the future and also (b) what it would be like to live in such a world.”

To set a vision for MPDs where they significantly change both the nature of the urban spaces around them, as well as perceptions and mental models that citizens have towards public displays, the author especially engages in cognitive speculation in projecting how MPDs might characterize our future. The concepts of mapping, arbitration and deterministic use are then practical manifestations of that cognitive speculation process, and act as anchors to allow pragmatic experimentation.

Even though the prototypes presented in Chapter 3 faced challenges in terms of the mental models they attempted to evoke, it can also be said that mental models in general are in a constant flux. When participants of an in-the-wild evaluation see it hard to imagine mobile devices being used in new ways, at the same time, new commercial solutions allow for example deeper connection between a Bluetooth-enabled smartphone and a car. Another example is the delivery of magazine content through a tablet computer instead of the passive paper form factor. Finally, the Google Glass is an urban computing artefact, which faces severe problems in terms of social acceptance due to its novel usage model as a combination of a wearable and a video capturing device. Thus, new technologies that are adopted as parts of everyday practices keep shaping the mental models and collective understanding, allowing new technological solutions to leverage this constant development.

Earlier in this dissertation, a question was raised for application-led research involving dedicated domain experts, so an apt question would be: Which domain experts benefit from the design space of this dissertation and its operationalizations? In the author's opinion, one rather obvious answer is that the design space can inform future urban planning. This is beneficial, since the more holistically public displays can be integrated into urban planning processes as a candidate technology, the deeper their integration into the resulting urban space and the sociocultural practices therein can potentially be. By striving to inform urban planning, the design space can also be seen as a practical example of the new kind of 'city making', emphasized by Brynskov *et al.* (2014).

As a final argumentation, MDPs represent only one instance in a constant chain of the so-called *disruptive innovations* that aim to significantly change urban spaces and the associated practices at the moment of writing this dissertation. AirBnB is an example of a service that aims to disruptively change how citizens perceive accommodation services. Uber allows direct communication between people in need of a taxi and people who happen to operating a car service with their personal car at a time, disruptively aiming to cut out the professional taxi service as a stakeholder. Finally, the autonomous car concept by Google aims to re-invent car-based transportation, essentially rendering the concept of owning a car meaningless. What all these disruptive innovations have in common is that they strive to significantly change how we perceive and experience urban spaces, and while not all of them will succeed, some will. And that is how new technologies shape the cities of tomorrow.

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491. Rossi, Pekka M. (2014) Integrated management of groundwater and dependent ecosystems in a Finnish esker

492. Sliz, Rafal (2014) Analysis of wetting and optical properties of materials developed for novel printed solar cells

493. Juntunen, Jouni (2014) Enhancing organizational ambidexterity of the Finnish Defence Forces' supply chain management

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