Aalborg Universitet

Designing Mobile Interactions: The continual convergence of form and context

Volume 1

Kjeldskov, Jesper

Publication date:
2013

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Kjeldskov, J. (2013). *Designing Mobile Interactions: The continual convergence of form and context: Volume 1*.

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Volume I

Designing mobile interactions

the continual convergence of form and context

Jesper Kjeldskov

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Volume I

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Designing mobile interactions - the continual
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Aalborg den 31 januar, 2013

Eskild Holm Nielsen

Dekan

This thesis has been accepted by the Faculty of Engineering and Science at Aalborg University for public defence in fulfillment of the requirements for the doctoral degree in science The defence will take place at Aalborg University in Auditorium 0.1.95, Selma Lagerlöfs Vej 300, on 29 May 2013 at 1.00 pm.

Aalborg, 31 January, 2013

Eskild Holm Nielsen

Dean

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Preface

At the end of 2010 more smartphones were, for the first time, being sold worldwide than personal computers, hailing the coming of the ”post-PC” era. This enormous uptake of mobile computers has had a huge impact on the way we perceive and use these technologies in our work and private spheres. Interactive mobile systems and devices have become functional design objects that we care deeply about the look, feel and experience of, and that we orchestrate in concert with a plethora of other computing technologies in our everyday lives. If such systems and devices are to be successful, they need to be designed to fit into the greater whole, or digital ecosystem, of other devices, systems and services that are part of the contextual richness of the world that surrounds us. This is, in my opinion, not achieved well through traditional methods of user-centered design and usability engineering. Instead, it calls for designerly approaches to interaction design that help us create new desired practice, design for wholes rather than just focussing on the parts, and deal with the often ill-defined and changing goals emerging from the process.

As a particularly important source of inspiration for developing such approaches to interaction design, I have always been fascinated by thoughts and practices in the discipline of architecture, especially the practice of embracing a contextual view and approach. The relationship between interaction design and architecture has been addressed previously by others, but in my opinion, there is still much to be learned from architectural design about how to think about and do interaction design. Looking at the design of mobile interactions as a continual convergence of form and context is an attempt to provide this designerly approach to thinking and doing interaction design, inspired by thoughts and practices in architecture. Through this approach, I seek to explore the view that most activities are unbounded and situated in dynamic contexts, and that the relationship between context and form is therefore a continually changing one requiring that design is inherently cyclic, able to deal with emergent and changing goals, and about construction of context as well as form.

My interest in mobile computing and telecommunication began twenty years ago, around 1992, when I first had the occasional opportunity to borrow a laptop computer and a portable car-phone while on the road with a band. Although they were bulky, heavy and expensive to use, I got the immediate feeling that these kinds of technologies were going to play a major role in our everyday lives in the future. I often spent a lot of time away from home: staying with family, at the library, commuting on public transport; or on the road with bands: waiting at music venues and cafés, backstage, wherever we were lodging that day or weekend. In those days I was not really interested in computers – simply because they did not fit into the context of my everyday life. With the availability of laptops and mobile phones that all changed. Suddenly I found my mobile and nomadic life empowered by technologies that in earlier forms had been of little value to me away from my desk at home. But what really had an impact on my thoughts about the potentials of these new technologies at the time was not just the many ideas about what I could possibly do with them, it was more the realisation that, in essence, my mobile

and nomadic life was not unique or unusual. In fact, it was very similar to the way most people spent a lot of their life: away, on the move, in-between, temporarily somewhere. This made me realise that mobile computing and telecommunication would probably be embraced by billions of people, and that this would change the world forever. Still, I underestimated the actual impact.

Over the two decades since, I have watched the evolution and enormous uptake of mobile systems and devices with great interest, enthusiasm and astonishment. I have, like so many others, embraced the potentials of mobile computing and the beginnings of the post PC era, and it has indeed changed my life. From my first mobile phone, the Nokia 2110 in 1995, which could actually fit in a pocket, and that I managed to forward emails to using SMS before texting became a common means of communication. To the Nokia 3110 in 1997, which had a graphical user interface that was actually a pleasure to use. To my first iPod in 2002 that allowed me to free myself from my CD collection and take my favourite music with me around the world. To my first camera phone in 2002, which had terrible picture quality but still captured a lot of moments that I keep in my photo collection today. To my first Apple iPhone in 2008, which completely changed my use of the Internet and became my primary device for managing email overnight. To my first iPad in 2010 that I bought with no particular purpose in mind, but which quickly replaced my use of a laptop at home.

My research interest in mobile interaction design began around 1999/2000 when I first started working with application design for the PalmPilot and with the potentials of Internet access on mobile devices through WAP. At the time, it quickly became clear to me that although mobile technology was maturing at a very fast pace, there were still major obstacles ahead of us in terms of interaction design that had to be addressed before non-specialists would be able to make use of it. Looking for inspiration, I decided to attend the Mobile HCI 2001 workshop in Lille, France. Back then this had not yet been established as a self-contained conference but ran as a small 1-day event as part of the IHM-HCI conference. The workshop was a great motivator for my research. I found every paper presented interesting and inspiring, and I really enjoyed the drive and enthusiasm of this new and vibrant research community. Returning from the conference I was hooked on mobile interaction design and began writing on a submission for the next conference straight away. The resulting paper, "Just-in-place information" became my first publication on mobile interaction design, and the notion of indexical interaction design addressed in it set the foundation for my future collaboration with Steve Howard and Frank Vetere's group at The University of Melbourne. It also later led to an early career research grant in 2004, and went on to be published in a leading HCI journal.

The Mobile HCI workshop in 2001 also led to an interest in mobile interaction design evaluation, which I began investigating together with Mikael B. Skov and Jan Stage. Together with Jan I also investigated system analysis techniques for mobile software development.

Later in 2001, on Mikael's suggestion, I visited the Interaction Design Group at The University of Melbourne in Australia for the first time and gave a talk about my ideas for mobile interaction design research. This visit led to a long-lasting (continuing) research collaboration where I was fortunate enough to spend four semesters in Australia over

the years that followed, working on projects such as TramMate, Mediating Intimacy, Customers of the Future, eSpective, and Indexing to Situated Interactions, which are all featured in this thesis. It was also during this time that I met Connor Graham, and we compiled our Mobile HCI research methods survey article for the Mobile HCI 2003 conference. It was also while in Melbourne that I met my wife, the lovely Jeni Paay.

Over the years, I have worked particularly closely with Steve, Frank, Mikael, and Jeni. Together with Steve and Frank I investigated the use of mobile technologies for mediating close personal relationships. Steve also spent 6 months in Aalborg in 2005, during which my thinking about interaction research significantly matured, and the groundwork for much of the research reported in this thesis was laid (over several bottles of red wine). Mikael and I went from working with evaluation techniques to focussing more on interaction design and studying the broader use of mobile and pervasive technologies in various domestic settings (over several bottles of beer). Together with Jeni, I developed the concept of indexical interaction design further, and began exploring the use of sketching and other general design techniques in mobile interaction design, drawing on her background in architecture, (over several bottles of champagne). These collaborations have all been essential for the research results presented in this thesis.

Around 2006, Steve and I began discussing the need for mobile interaction design research to cast a wider perspective on the orchestration of multiple devices, rather than just looking at the design and use of individual artefacts in isolation. This interest in a broader perspective led me to accept an offer in 2007 to lead a research group in Sydney, Australia, where we would be able to work in this area. Here I was extremely fortunate to meet and work closely with Kenton O'Hara, who joined the team a few months after me. Working with Kenton led to renewed inspiration and a new level of depth and detail in my work and thinking, which greatly influenced the way I subsequently developed and wrote this thesis, after returning to Aalborg.

The thesis presents the core of my research contributions in the area of mobile interaction design. It consists of a position summary about the design of mobile interactions as a continual convergence of form and context. This is followed by the research methods survey from Mobile HCI 2003 mentioned earlier, and twenty-one other research articles divided into five parts. The first part is about studying and analysing aspects of context relevant for mobile interaction design. The second part is about the process of designing and building interactive mobile systems that are grounded in their context. The third part is about techniques for studying the user experience of mobile interaction design in context. Part four, slightly different in nature from the previous three parts, describes five prototype systems and is about the use of context in the implementation of concrete interactive systems. Finally, part five is about describing and understanding the relationships between interactive mobile systems, users, and their context.

As described, the research presented in the thesis is the result of several collaborations with colleagues and students between 2001 and 2010. Most of the research was developed and carried out at the Department of Computer Science at Aalborg University and the Department of Information Systems at The University of Melbourne. I wish to thank these institutions for their support and, in particular, thank my closest colleagues and

co-authors over the last decade: Jeni Paay, Mikael B. Skov, Steve Howard, Jan Stage, Frank Vetere, Connor Graham, Kenton O'Hara, and Sonja Pedell. My collaborations with Mikael B. Skov, Steve Howard, and Jeni Paay have been particularly inspiring and productive, and have greatly informed the thinking leading to this thesis. I also thank, in particular, Lars Mathiassen and Steve Howard for detailed feedback and valuable discussions on early drafts. I also want to thank Erik Frøkjær for ongoing fruitful discussions of my work, and Ellen Christiansen for introducing me to the works of Christopher Alexander. I also want to thank the Masters students in Human-Computer Interaction that have co-written papers presented in the thesis: Rahuvaran Pathmanathan, Claus M. Christensen, Klaus Kjeldsen, Niels Husted, Jacob Nørskov, and Kenneth Pedersen.

The position summary in Chapter 1 was developed and written between early 2010 and 2012. Being back in Aalborg gave me the opportunity to revisit my own research and think about it in a broader perspective while working in a positive, fun and supporting environment. For this I thank my colleagues at the Department of Computer Science, especially the members of the Information Systems group/Centre for Socio-Interactive Design: Ivan Aaen, Peter Axel Nielsen, Jeni Paay, John S. Persson, Jeremy Rose, Mikael B. Skov and Jan Stage, as well as the group's Ph.D. students during this period of time Anders Bruun, Lise T. Heeager, Karsten Jahn, Kenneth Nielsen, Dimitrios Raptis and Henrik Sørensen.

Finally, I thank my wife Jeni for putting up with me, and for giving me the space for thinking and writing needed to produce this thesis.

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Position summary

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Chapter 1

Designing mobile interactions
- the continual convergence of form and context

Jesper Kjeldskov

Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world

– Albert Einstein

Abstract. This thesis presents a contextual approach to designing contemporary interactive mobile computer systems as integral parts of ubiquitous computing environments. Interactive mobile systems, services and devices have become functional design objects that we care deeply about. Although their look, feel and features impact our everyday lives as we orchestrate them in concert with a plethora of other computing technologies, these artefacts are not well understood or created through traditional methods of user-centred design and usability engineering. Contrary to more traditional IT artefacts, they constitute holistic user experiences of value and pleasure that require careful attention to the variety, complexity and dynamics of their usage. Hence, the design of mobile interactions proposed in this thesis transcends existing approaches by using the ensemble of form and context as its central unit of analysis. As such, it promotes a designerly way of achieving convergence between form and context through a contextually grounded, wholeness sensitive, and continually unfolding process of design.

1. INTRODUCTION

"Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world" (Einstein 1931). In computing and interaction design today, imagination is every bit as important to advance our knowledge and practices as it was to science in the 1930's. Without imagination and creativity we are not able to move beyond how we think and do today, towards the thinking and doing of tomorrow. This is the timeless way of designing, and it is my starting point for looking at the design of mobile interactions. How can we imagine thinking and acting differently in order to enable ourselves to make future generations of interactive computer systems and devices fundamentally better than the ones we have now? Our current landscape of interactive technologies has itself grown out of paradigmatic shifts in the way we thought about computer systems and did systems development in the past. These shifts brought computing into areas like the workplace, the home office, and into the private sphere, and it made computing about things like work support, collaboration, communication, media consumption, and social networking. But where do we go from here? How can we, once again, reach beyond our presently established ways of thinking and doing, and actively advance the design of interactive computer systems of tomorrow? In this thesis I am going to address this question by revisiting my research contributions within the area of interaction design for mobile computer systems.

One of the things that makes mobile computing an interesting topic of research and design is that the area is strongly driven by innovation, characterized by rapidly evolving use, and has enormous market potential and growth. New technologies are constantly being developed, new use domains are constantly being explored, and successful new ideas and applications reach millions of users. In fact at the end of 2010 more smartphones were, for the first time, being sold worldwide than personal computers, with more than 100 million units shipped in the last three months of that year alone. Reflecting this dynamic and rapidly evolving nature of the area, the industrial lead position has been passed on several times within only a decade, from Palm to Nokia to Apple, and possibly soon to Google, and is most likely to be passed on again in the future. This obviously motivates researchers and designers to keep innovating and developing new technology and applications. A primary driver of mobile technology development has been the enormous uptake of interactive systems and devices for work as well as for leisure. Mobile phones have long been something almost everyone owns at least one of and uses extensively for personal purposes and not just for work. With Internet and multimedia-enabled phones such as the Apple iPhone and phones running Google's Android operating system, smart phones have now firmly reached this mass market too and are no longer something exclusively for a small elite of business professionals. The uptake of mobile technology in our work and private spheres has had a huge impact on the way we perceive and use these technologies. They are no longer just computers on batteries. They have become functional design objects, which we care deeply about the look, feel and experience of, and that we juggle in multitude in our everyday lives. Hence, work in the area of mobile computing has rapidly evolved from being strongly an *engineering* profession to being, at least, equally strongly a *design* profession where the contextual user experience of interactive mobile systems and devices, and the digital

ecosystems they are forming, is of utmost importance. This presents the field of mobile interaction design with new challenges forcing us to seek beyond user- or technology-centred approaches.

Being a design profession is different from being an engineering profession. It involves careful engineering, but where engineering is about implementing a solid solution to a problem, design is about also understanding and defining that problem in the first place, and exploring a wide range of solutions before choosing which one to implement. This requires different methods and techniques than the ones taught at engineering schools. It requires techniques that sit at the intersection between technology and art – that support the process of exploring a problem and a design space by generating, communicating and reflecting on ideas, and facilitate choosing between multiple paths of possible solutions. Traditional usability engineering and user-centred design approaches do not facilitate such opportunity seeking ideation and elaboration, but are better at supporting decision making for further reduction and specification of a particular solution.

Mobile computing is a relatively new field of research with little more than three decades of history. During its lifetime it has expanded from being primarily technical to now also being about usability, usefulness and user experiences. This has lead to the birth of the vibrant area of *mobile interaction design*[1] at the intersections between, among others, mobile computing, social sciences, human-computer interaction, industrial design, and user experience design. However, the field of mobile interaction design is still young and immature. Growing out of the "Mobile HCI" community of the early 2000s, it has survived infancy and become an acknowledged part of the established research area of computing with a notable presence in mainstream HCI literature and with its own conferences and journals. But it still doesn't have a strong and unified identity. There is no well-defined methodological and theoretical base for the design of mobile interactions, or even a catalogue of best practices, and there are no well-defined goals or benchmarks for good mobile interaction design research. This is not to say that there is not a lot of good mobile interaction design and research taking place. There is indeed. It is, however, rather fragmented, and rather than an organised community it can, like the field of interaction design generally, better be characterised as "being composed of a number of roving tribes who occasionally encounter one another, warily engage, and, finding the engagements stimulating, remain open to other encounters" (Erickson 2006 p. 301). The advantage of this might be a high level of autonomy, but the disadvantage is less than optimal collective accumulation of knowledge and impeding our ability to leap forward in a pace beyond small incremental steps of each individual piece of research.

This thesis is an attempt to respond to these new challenges by suggesting a holistic approach that rethinks and ties together central activities of interaction design into an ongoing process evolving around the central concept of converging form and context. By convergence I simply mean the combination of two or more things that in concert make up something new that is bigger than the sum of the contributing parts. In my understanding of form and context I subscribe to the fundamental view promoted

1) In line with Preece et al. (2002) I use the term mobile interaction design rather than mobile human-computer interaction because I believe it reflects the emerging research community better. Interaction design includes human-computer interaction, as well as other disciplines, but emphasises an overall goal that is more constructive in nature and that acknowledges mobile computing as a design profession.

by Christopher Alexander in his 1964 "Notes on the Synthesis of Form". According to Alexander, design is "an effort to achieve fitness between two entities: the form in question and its context" (Alexander 1964 p. 15). "Form" is the response to a situation, or problem, whereas "context" defines or frames this situation or problem. Hence, in this use of the term, form does not just mean physical shape, but unites *shape, look, function* and *content*. Using this conceptual optic the design of mobile interactions is about considering the ensemble of particular forms (i.e. interactive mobile systems) in relation to their context (i.e. users, technology, settings, activities etc.).

Figure 1. Form and context in the design of mobile interactions

Following Alexander's line of thought, when we deal with the process of design "the real object of discussion is not the form alone, but the *ensemble* comprising the form and its context" (Alexander 1964 p. 16, italics added). Secondly, but often overlooked, the quality as a whole of a designed form-context ensemble can be influenced by changing the form, but also by changes in the *context*. In direct continuation of this, the views promoted in this thesis build on the belief that the design of mobile interactions should embrace the potentials of designing for wholes, rather than individual parts, and that the notion of form-context ensembles provides a suitable higher-level unit of analysis for such transcension of focus and scope beyond user- or technology-centeredness.

The work presented in this thesis aspires to contribute to the accumulation of a theoretical and methodological body of knowledge about mobile interaction design. It is grounded in a series of specific studies involving interaction design for concrete mobile systems and devices, and uses this foundation to 1) shape a holistic perspective on the process of mobile interaction design in which the main activities of studying, analysing, designing and building interactive mobile systems evolves around the central unity of form-context convergence, and 2) provide insight about each of these individual activities of mobile interaction design, and their contribution to the unfolding whole.

This first chapter presents the background and my thinking about the design of mobile interactions and summarizes the work included in the following 22 chapters. As a starting point, in section 2, I trace the history of mobile computing through seven distinct phases, and introduce the discipline of interaction design. This is followed by a description of the most notable existing design approaches within this field. In section 3, I describe the starting point for my own research on the design of mobile interactions in the early 2000s, and outline the five research topics that I have worked with. I then describe two emerging challenges for the design of mobile interactions: 1) transcending beyond the dichotomy of people- or technology- oriented research and design, and 2) widening

the scope beyond the individual mobile device and an individual user's interaction with it. In response to these, in section 4, I discuss the need for doing, and thinking about, interaction design in *a designerly way* rather than in a traditional scientific way. I do this by drawing on thoughts in the literature on design research largely from outside the field of interaction design, such as Schön's notions of problem-setting and reflection-in-action (1983), Pepper's notion of contextualism (1942), Pierce's notion of abductive reasoning (1931-58), and Alexander's notion of unfolding wholeness (2002-05), and showing how these thoughts can help enrich the way we think about mobile interaction design. This is followed by a critical discussion of the established user-centred design model, leading to a series of proposed changes. In section 5, I then present and discuss, as an alternative, the design of mobile interactions as a matter of continual convergence of form and context. In section 6, I present an overview of my individual research contributions, and relate these to the central activities, transitions and outcomes of the design of mobile interactions as a continual convergence of form and context. Finally, section 7 summarizes the main conclusions of my work.

2. BACKGROUND

To ground my work on the design of mobile interactions I will first briefly trace the history of mobile computing. The purpose of this is to map out the origins of this field of research and design, show how it is continually evolving, and illustrate the influence of careful and innovative mobile interaction design at different points in time. This is followed by an introduction to the discipline of interaction design and its established design approaches.

2.1. Mobile Computing

Mobile computing is a significant contributor to the pervasiveness of computing resources in modern western civilisation. In concert with the proliferation of stationary and embedded computer technology throughout society, mobile devices such as cell phones and other handheld or wearable computing technologies have created a state of ubiquitous and pervasive computing where we are surrounded by more computational devices than people (Weiser 1991). Enabling us to orchestrate these devices to fit and serve our personal and working lives is a huge challenge for technology developers, and "as a consequence of pervasive computing, *interaction design* is poised to become one of the main liberal arts of the twenty-first century" (McCullough 2004, italics added).

The field of mobile computing has its origin in a fortunate alignment of interests by technologists and consumers. Since the dawn of the computing age there has always been technological aspirations to make computing hardware smaller, and ever since computers became widely accessible there has been a huge interest from consumers in being able to bring them with you (Atkinson 2005). As a result, the history of mobile computing is paved with countless commercially available devices. Most of them had short lifespan and minimal impact, but others significantly pushed the boundaries of engineering and interaction design. It is these devices, and their importance, that I wish to emphasize here.

The history of mobile computing can be divided into a number of eras, or waves, each characterized by a particular technological focus, interaction design trends, and by leading to fundamental changes in the design and use of mobile devices. In my view, the history of mobile computing has, so far, entailed seven particularly important waves. Although not strictly sequential, they provide a good overview of the legacy on which current mobile computing research and design is built.

1. Portability
2. Miniaturization
3. Connectivity
4. Convergence
5. Divergence
6. Apps
7. Digital ecosystems

The era of focus on *Portability* was about reducing the size of hardware to enable the creation of computers that could be physically moved around relatively easily.

Miniaturization was about creating new and significantly smaller mobile form factors that allowed the use of personal mobile devices while on the move. *Connectivity* was about developing devices and applications that allowed users to be online and communicate via wireless data networks while on the move. *Convergence* was about integrating emerging types of digital mobile devices, such as PDAs, mobile phones, music players, cameras, games, etc., into hybrid devices. *Divergence* took an opposite approach to interaction design by promoting information appliances with specialised functionality rather than generalized ones. The latest wave of *apps* is about developing matter and substance for use and consumption on mobile devices, and making access to this fun or functional interactive application content easy and enjoyable. Finally, the emerging wave of *digital ecosystems* is about the larger wholes of pervasive and interrelated technologies that interactive mobile systems are increasingly becoming a part of.

Portability

The first mobile computers, the precursors to present time's laptops, were developed in the late 1970s and early 1980s inspired by the portability of Alan Kay's Dynabook concept from 1968 (Kay 1972). The Dynabook concept was originally thought of as a machine for children, but observant entrepreneurs, such as the founder of GRiD Systems, John Ellenby, quickly realised that the starting point for something that innovative would have to be "the customer with the most money and the most demanding need" (Moggridge 2007).

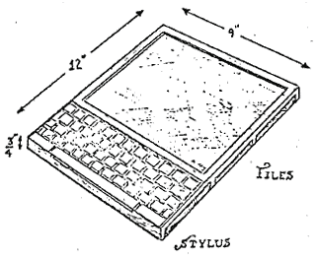

Figure 2. Alan Kay's Dynabook: "a personal computer for children of all ages" (Kay 1972)

The first laptop computer was the GRiD Compass 1101 designed by Bill Moggridge as early as 1981 in response to the design brief of fitting within half the space of a briefcase (Moggridge 2007, Atkinson 2005). The Compass had a 16MHz Intel 8086 processor, 256K DRAM, a 6-inch 320x240 pixel flat screen display, 340kb bubble memory, a 1200 bit/s modem, weighed 5 kg and ran its own graphical operating system called GRiD OS. It was primarily sold to the U.S. government and was, amongst others, used by NASA on Space Shuttle missions during the early 1980s, and in combat. The GRiD Compass featured a stunning forty-three innovative features in its utility patent, including the flat display and hinged screen. The first portable computer to reach real commercial success, however, was the suitcase-style Compaq Portable from 1982, which as the first official IBM clone could run MS-DOS and standard PC programs. In 1988 Grid Systems also developed the first tablet computer, the GRiDpad, initiated and led by Jeff Hawkins who later designed the first PalmPilot and founded Palm Computing.

GRiD Compass 1101 (1981)

Compaq Portable 1 (1982)

GRiDpad 1910 (1989)

Figure 3. Mobile computers in the 1980-90s

In terms of design longevity and impact, Bill Moggridge's work on the first laptop computer and Jeff Hawkins' work on the GRiDpad illustrates the value of careful and well-considered interaction design in mobile computing. The GRiD Compass was superior in terms of its design and performance for a decade. It defined the folding design still used in today's laptops 30 years later, and its basic form factor was not surpassed until the Apple PowerBook 100 introduced the, now standard, clamp-shell design and integrated pointing device in 1991. The basic design of the GRiDpad paved the way for tablet computers and handheld devices such as the Apple Newton, the PalmPilot, and even the iPad over 20 years later.

Miniaturization

By the early 1990s the size of computer hardware had reached a point that allowed radically new and smaller form factors of mobile computers to evolve and emerge on the market. These predominantly handheld devices were labelled palmtop computers, digital organizers, or "Personal Digital Assistants" (PDAs). PDAs differed from laptop PCs by being truly mobile and something that the users could operate while actually moving around physically. They were not thought of as alternatives to desktop or laptop computers but rather as small and lightweight supplemental devices for busy businessmen spending some of their time away from their PC. The first PDA was the Apple Newton from 1992. In 1997 the first PalmPilot was introduced, and in 2000 Compaq released the iPAQ Pocket PC. Whereas the focus of laptop computing was predominantly on portability and mobile access to documents and applications available on desktop computers, palmtop computing introduced an additional focus on applications and interaction styles designed specifically for mobile devices and mobile users.

Apple Newton (1992)

PalmPilot (1997)

Psion 5 (1997)

Compaq iPAQ (2000)

Figure 4. Mobile computers in the 1990-00s

The PDA generation of mobile devices represented a number of distinct interaction design choices and form factors. Most notably they introduced the combination of a relatively small touch-sensitive screen and a separate pen (or stylus) for user interaction. Using the stylus the user could interact with content directly on the screen and enter text via an on-screen keyboard or through handwriting recognition software. Other interaction design innovations included function buttons for accessing pre-defined applications and functions, navigation keys for operating menus, and the "one-click" dock for synchronizing with a stationary computer and for charging. While the Psion series 3 to 5 replicated a "laptop in miniature" design, the Newton, PalmPilot and iPAQ all represented a fundamentally new mobile computing form factor where the majority of the device's surface was used for its display. In terms of interaction design process, the PalmPilot in particular was a product of careful and detailed rethinking of the emerging class of handheld computers; what they should look and feel like, what functions they should perform, and how they should perform them. As an example, the creator of the PalmPilot, Jeff Hawkins, later explained how he carried blocks of wood with him in different sizes and shapes until he had reached the perfect physical form for the device (Bergman and Haitani 2000).

With the emergence of PDAs came also new categories of applications developed specifically for mobile devices and users. The devices each had their own operating systems, optimized for their particular screen sizes and input capabilities, and a suite of standard applications for calendars, contacts, note taking, and email. Adding to this, a wide range of 3rd party applications soon became available for purchase, or, as something new, downloadable via the Internet. By the late 1990s application development specifically for mobile devices was an acknowledged research area and profession, and in 1998 the first international workshop on Human-Computer Interaction with Mobile Devices (Mobile HCI'98) was held in Glasgow specifically addressing the emerging challenge of interaction design and user experiences for mobile devices, systems and services.

Connectivity

The third wave of mobile computing had its origins in wireless telecommunication. As early as 1973 a Motorola team led by Martin Cooper developed and patented a handheld mobile phone concept that led to the first commercial mobile phone small enough to be carried, the DynaTAC 8000X, in 1983.

Figure 5. The first handheld cell phone: Motorola DynaTAC 8000X (1983)

In the 1980s and early 1990s mobile phones were not really considered to be computers. However, with the introduction of the digital GSM mobile phone system in 1991, which also included the Short Message Service (SMS) communication component, the

complexity and functionality of handsets began evolving rapidly. So did the uptake of mobile phone technology by the broad population worldwide. This meant that mobile phone developers were suddenly faced with a huge challenge of interaction design not only for making phone calls, but also for handling contacts, calendars, text-based messages, and browsing the Internet. In the late 1990s interaction design for mobile phones was unarguably dominated by the work at Nokia, which led to a series of groundbreaking handsets. The challenges of the time were to design for tiny low-resolution displays and for input capabilities limited to a 12-key numeric keypad along side a small number of function and navigation keys. One of the first mobile phones explicitly resulting from a careful process of interaction design at Nokia in the 1990s was the Nokia 3110. It introduced a simple graphical menu system and the "Navi-key" concept for simplifying user interaction – an interaction design that reached the hands of more than 300 million users through subsequent Nokia handsets (Lindholm 2003). In 1999 the basic interaction design of the Nokia 3110 was extended with T9 predictive text for SMS messaging, games, customisable ring tones, and changeable covers for the extremely successful Nokia 3210.

In the late 1990s, the enormous, and completely unexpected, uptake of the Short Message Service (SMS) inspired attempts to bring the Internet to mobile handsets too. This led to the development of the Wireless Application Protocol (WAP) allowing simplified websites to be viewed on small displays and paving the way for Internet access on mobile devices. The first mobile phone to feature a WAP browser was the Nokia 7110. In response to the need for scrolling through long WAP pages it also featured the first "Navi-roller" thumb wheel. As an interesting example of interaction design, the 7110 also featured a *spring-loaded* cover concealing the keypad, which was inspired by the film The Matrix where the main character uses an earlier Nokia phone modified by the film's production crew to have this functionality. "Life imitating art" (Wilde 1889) you could say. WAP, however, never lived up to its expectations due to slow data transfer and poor usability (Ramsay and Nielsen 2000, Nielsen 2000, Kjeldskov et al. 2002) and was soon superseded by access to the real web on mobile devices. Nevertheless, mobile phone design in the 1990's had a fundamental and lasting impact on the future of mobile computing to come.

Nokia 3110 (1995) Nokia 3210 (1999) Nokia 7110 (1999)

Figure 6. Three mobile interaction design milestones: Navi-key, T9, and WAP

Convergence

One of the most interesting eras of mobile computing began when different types of specialized mobile devices began converging into new types of *hybrid* devices with fundamentally different form factors and interaction designs. The first phase of this was the emergence of "smart phones", which combined the functionality of a PDA with that of a mobile phone. The development of smart phones involved exploration of a wide range of form factors and interaction designs and led to a series of innovative solutions. Many of these involved designs where the physical shape of the device could be changed depending on what the user wanted to use it for. Other designs, like the Blackberry, introduced a "wide-body mobile phone" form factor with a PDA size display and a miniature QWERTY keyboard in place of the traditional 12-key numeric keypad. The first smart phone that as well as making phone calls could also be used for calendars, addresses, notes, e-mail, fax and games was the IBM Simon from 1992. It had no physical buttons but only a touch screen, which could be operated with a finger or a stylus.

IBM Simon (1992) Nokia 9000 (1996) Ericsson R380 (2000) Blackberry 5810 (2002)

Figure 7. Smartphones exploring different physical form factors and interaction styles

The second phase of convergence combined mobile phones with various rich media capabilities, such as digital cameras, music players, video recording and playback, and television and radio reception. Whereas smart phones were attractive for business professional's work activities and productivity, multimedia phones were attractive for everyday people's leisure, fun and socialising.

The most notable example of convergence for leisure was the invention of the camera phone. The first mobile phone to feature a digital camera was the Sharp J-SH04 from 2001. It was only available in Japan through the i-mode mobile Internet service, but the rest of the world soon followed. Two years later more camera phones were sold than digital cameras, and in 2006 half the world's mobile phones had a built-in

Sharp J-SH04 (2001) Nokia N-Gage (2003) Nokia N90 (2005) Sony Ericsson W600 (2005)

Figure 8. Converged mobile devices: camera-phones, game-phone and walkman-phone

camera – making Nokia the biggest brand of digital cameras and forcing prominent brands such as Minolta and Konica out of the camera business. By 2009 there were more than 1.9 billion camera phones in existence, and mobile phone photography had already had a huge social impact through new ways of capturing and sharing photographs over the Internet (cf. Kindberg et al. 2005, Gye 2007). Whereas early camera phones were clearly phones with cameras, novel interaction design led to several converged devices truly blurring the boundaries between the two (Murphy et al. 2005/chapter 23). As an example, it can be hard to tell if the Nokia N90 is a phone or a camcorder. Another converged functionality to become widely available on mobile phones was the ability to listen to digital music. Most notably Sony re-launched its successful "Walkman" brand of the 1980s in the shape of the converged Sony Ericsson W600 in 2005. With the W44 multimedia phone from 2006, they even went a step further and extended video and music playback with the ability to watch and listen to digital TV and radio. Convergence also led to the creation of hybrid game-phones like the Nokia N-Gage with form factors resembling handheld game consoles.

The fundamental driver behind the trend of convergence is that mobile user experience is proportionally related to the functional scope of interactive mobile devices and systems: "more means more" (Murphy et al. 2005/chapter 23). As a consequence, convergence has often been criticised for generating weak general solutions with usability comparable to the Swiss army knife: clumsy technology with a wide range of functions, none of which are ideal in isolation (see e.g. Norman 1998, Bergman 2000, Buxton 2001). However, in my view the real strength of convergence should not be sought in the simple availability of several functions implemented in the same device. Rather it should be found in the potential creation of something new and hybrid that facilitates use that wasn't possible before, like for example taking pictures and sharing them immediately with your friends, browsing the Internet on your phone, or purchasing music directly on your iPod.

Divergence

Contrasting the convergence approach, the trend of *divergence* suggested a single function/many devices or "information appliance" approach where each device is "designed to perform a specific activity, such as music, photography, or writing" (Bergman 2000). The driving force behind this line of thought is that having a wide range of good specialized tools is better than a general one that does not perform any task particularly well. Specialized tools facilitate optimisation of functionality over time and refinement of well-known paradigms of use. The fundamental view promoted by the trend of divergence is that mobile user experience is *inversely* proportionate to the functional scope of interactive mobile devices and systems: "less is more" (Murphy et al. 2005/chapter 23).

The 2000s saw the emergence a wide range of diverged mobile devices dedicated to do one specific task really well, particularly mobile music players, video players and games. Of course functionally dedicated mobile devices were not a new phenomenon as, for example, early mobile devices such as pocket calculators, cell phones, GPS receivers, digital cameras, and PDAs could unarguably be classified as information appliances too. But what was interesting about the trend of divergence in the early 2000s was that it

Apple iPod (2001) Archos Gmini (2004) Sony PSP (2004) iPod Nano (2010)

Figure 9. Specialised mobile media and gaming devices

was a deliberate interaction design choice and not a technological necessity. Probably the most legendary example of an information appliance was the Apple iPod from 2001. Although not the first mobile digital music player, its interaction design, including the integration with iTunes and later the iTunes Music Store, fundamentally changed global music consumption and purchasing behaviour. Although most mobile phones on the market in the mid 2000s were able to play MP3 files, people still preferred to carry an additional device, the iPod, for playing their music. It provided a better user experience for that particular task, and the device itself had become a popular fashion item. In late 2011 the total number of iPods sold had exceeded 300 million units. Other diverged mobile devices included video players like the Archos Gmini from 2004, the Sony PSP game and video console, and later versions of the iPod extended with video playback capability and multi-touch interaction design.

The interaction design challenge of a diverged mobile device is considerably different from that of a converged one because its functional scope is much narrower. However, as diverged devices are by definition typically used in concert with a plethora of other interactive devices and systems unknown to the designer, there is a huge interaction design challenge in supporting good and flexible integration and "convergence-in-use" (Murphy et al. 2005/chapter 23).

Apps

In June 2007 Apple launched the iPhone. Like many of its contemporaries this was a converged mobile device functioning as a camera phone, portable media player, and Internet client with e-mail, web browsing, and high-speed wireless network connectivity. However, rather than being just another incremental step in the evolution of converged mobile devices, the iPhone represented a significant rethinking of the design of mobile interactions and a series of notable interaction design choices. It featured a large high-resolution capacitive multi-touch display with simple gesture capabilities such as swiping and pinching, and departed completely from the predominant use of physical keys and a stylus for text entry and interaction. Instead of navigating large and deep hierarchies of menus, the user experience was much more fluid and aesthetic, and the phone was both extremely easy and pleasurable to use. The iPhone also featured a number of embedded context sensors, which changed the orientation mode of the display depending on how it was held, as proposed in a UIST conference paper by Hinckley et al. (2000), and changed the mode of the phone application when held close

to the face during a call. The later inclusion of GPS and a digital compass extended this "context-awareness" capability to also enable location-based services.

On the software side, the iPhone's web browser actually made it possible to access web content on a mobile device with a positive user experience, and many soon described handling email on the iPhone as favourable compared to its desktop counterparts. Dedicated applications provided direct access to watching video content from YouTube and purchasing music from the iTunes Store. In concert, this meant that people actually started using their mobile device as a *preferred* gateway to the Internet, rather than as a last resort. Consequently iPhone OS dominated the total amount of mobile web traffic worldwide by mid 2009 (Admob 2009). In addition to this, data and media content could be integrated seamlessly with the user's other devices and computers at home or at work through cloud computing services such as MobileMe in a seamless way never seen before in mobile interaction design, illustrating initial steps towards the creation of *digital ecosystems* of mobile and stationary computer systems connected through the Internet.

The iPhone completely redefined mobile computing and set new standards for mobile interaction design and user experiences that other companies, such as Google and HTC, still struggled to match up to 4 years later with the Android mobile operating system and associated online application store. In many ways, the iPhone was the device that mobile interaction design researchers had envisioned for a decade, and its enormous uptake worldwide, with over 310 million iOS enabled devices sold by the end of 2011, confirms that we were indeed right in our speculations about what people would want to do with mobiles – if only we could provide them with a good enough interaction design and user experience. The biggest impact of the iPhone, however, was not only in the interaction design of the device itself and in the high quality of its native applications. As it turned out, it was in the creation of an interaction design that provided users with easy access to a vast and unprecedented amount of *applications* for their mobile device.

In 2008 Apple launched the online "App Store" which provided a mechanism by which iPhone users could easily download, and pay for, third-party application content directly from their mobile device. These Apps span a range of functionalities, including social networking, productivity tools, personal utilities, games, navigation, and advertising for movies and TV shows. For creating this application content, an iPhone OS software development kit (SDK) was released for free along with a business model where Apple handles payments and distribution while leaving App creators with 70% of the profit. By 2012 more than 25 billion Apps had been downloaded from a selection of more than 500.000, making this hugely profitable for both Apple and for the individual third-party creators of particularly popular Apps, which in return has motivated the creation of even more application content. As an indication of the incredible size of this business, third party mobile software developers generated a total income of $2 billion by selling their products through the Apple App store in less than three years. Contrary to developing mobile applications in Java 2 Platform, Micro Edition (J2ME) or Qualcomm's Binary Runtime Environment for Wireless (BREW), developing in iPhone SDK involves no need for customizing applications for a vast range of different handsets, which means that more time can be spent on application design. Also, in sharp contrast to the generally horrific mobile phone user interfaces for installing especially J2ME software, the

iPhone provides not only a supply chain and billing model out-of-the-box but also an application shopping user experience that is *positive in itself*. Hence, prior to the iPhone, downloading and installing software onto a mobile phone or PDA was something only technology-savvy people would do. Today this is common practice for millions of users of all ages and computing experience.

As an interesting effect of the iPhone-approach to mobile interaction design, improving the hardware specification of devices was suddenly surpassed in importance in favour of improving the software that is available for them. This is evidenced in the pace and scope of software developments and updates compared to equivalent hardware ones. This is an important shift within the design of mobile interactions, and indicates that a level of stability has been reached in terms of physical form factors and basic input and output capabilities, in favour of a focus on *applications and content*.

Figure 10. The Apple iPhone and iPad (2007 and 2010)

Apple's success with the iPhone lead to a third endeavour within mobile computing, the iPad, which was released in April 2010. Initial media reaction was mixed, but commercial uptake was unprecedented, and the iPad was sold in over 2 million units in its first two months, reaching 15 million units sold by the end of the year. While Microsoft's explicit interaction design approach for PDAs and tablets had long been to replicate their desktop OS (Zuberec 2000), Apple took the opposite approach with the iPad tablet and based it on iPhone OS rather than MacOSX. This was a surprising move for many, admittedly including myself, but had the effect of reinterpreting, and subsequently redefining, the so-far troubled category of "tablet computers" into a new category of *mobile devices,* that are not just laptops without keyboards. Although criticised for being a closed system, the strength of the iPad lay in the user experience created through its meticulous interaction design, which invited the already growing community of iPhone interaction designers and application developers to explore the tablet form factor. Until then, nobody had cared to create web or native application content for tablets (Chen 2010), but with the iPad, tablets suddenly became one of the most interesting and promising mobile platforms on Earth. Consequently, after only one year of existence, there were more than 65.000 Apps available for the iPad.

Digital ecosystems

As we move into the second decade of the new millennium the challenges of mobile computing and interaction design continue to evolve. The technical capabilities of our mobile devices have improved significantly to the point where factors such as screen real estate, input capabilities, processing power, network speed and battery lifetime are much less of an issue than only half a decade ago. At the same time, we have also become rather skilled at designing for relatively small screens and for the different input capabilities of mobile devices. So much that millions of ordinary people are actually able to download and use the applications being developed, and are even willing to pay for some of them. To a large extent, therefore, we have now successfully solved the majority of problems facing mobile interaction researchers and designers in the past. However, as the history of all areas of computing have shown us, it is highly unlikely that we have reached an end point. As in the past, the technology and interaction design we are witnessing today is just the starting point for the continuing evolution of the technology and interaction design of tomorrow. But what are then the challenges and opportunities for the design of mobile interactions to come? What will the next wave of mobile computing be about?

Fuelled by the enormous interest and uptake of "post-PC devices" like smart phones and tablets by the general population, it is not unreasonable to speculate that a major platform shift away from desktop computing is imminent. Mobile devices are becoming more and more important and widespread. They will soon be the dominating point of access to the Internet, and in combination with the growth of cloud computing they will soon dominate peoples' use of computational power. Importantly, what we are witnessing here is not just the development of even smarter smart phones with improved abilities to imitate desktop PCs in miniature. It is a radical evolution of a major computing platform for new applications allowing us to do things that couldn't be done before. This may well be a genuine paradigm shift for mobile computing and mobile interaction design.

In my belief, the next wave of mobile computing and interaction design is going to be about the creation of *digital ecosystems* (Miller et al. 2010) in which mobile computing plays a central role in concert with other ubiquitous computing resources. This challenges us to move beyond considering interactive mobile devices, systems and services as entities that can meaningfully be designed and studied in isolation from the larger use context or artefact ecologies (Jung et al. 2008, Bødker and Klokmose 2011) that they are a part of. Yes, mobile computers, in various forms, play hugely important roles in most peoples' everyday lives, but they are not the only technologies and artefacts we make use of at home or at work, or in the space between. Most people use multiple mobile devices for different purposes, but they also use a multitude of stationary or embedded computer systems, at work, at home, in our cars, or in the city around us. In concert this makes up a rich digital ecosystem of interactive devices, systems and services often referred to as ubiquitous or pervasive computing, in which mobile computing is a central, but not the only, component. The challenge of designing mobile interactions in such ubiquitous and pervasive information societies is to facilitate the creation of interactive devices, systems and services that fit well into this ecosystem of other devices, systems and services, as well as into the rich new use practices, for work and leisure, created by these technologies and their users. Like any other type of ecosystem, understanding,

creating and maintaining digital ecosystems requires a holistic perspective on the totality and ecology of the system at play, and not just detailed views on each of its individual components. As argued earlier, it is my position that this cannot be achieved well through a technology- or a user-centred approach, but requires a change of the unit of analysis towards one that continually includes both these viewpoints.

The digital ecology wave of mobile computing will build on the achievements of previous eras within hardware miniaturization, connectivity, new form factors, input devices, interaction styles, applications, convergence, divergence and content, but it will broaden the scope to include the wider context of use and an explicit sensitivity for the contextual factors that influence the user experience. It is going to be about creating interactive devices, systems, and services that respond to the broad and diverse aspects of human life, and that not only provide utility and are easy to use, but also provide pleasure and value, and fit naturally into peoples' complex and dynamic lives of constantly changing settings and situations. My position here is that this will best be achieved through careful attention to the details, richness and dynamics of *form-context ensembles* during all phases of mobile interaction design and system development: from initial domain studies and analysis through creative design, implementation of actual interactive systems, evaluation studies and analysis of their outcomes.

2.2. Interaction design

I will now turn my attention towards the notion of interaction design. The term interaction design was coined by Bill Moggridge and Bill Verplank in the late 1980s, and is about "designing interactive products to support the way people communicate and interact in their everyday and working lives" (Sharp et al. 2007 p. 8), or more broadly about "the design of everything that is both digital and interactive" (Moggridge 2007 p. 660) with particular attention to its subjective and qualitative aspects. In other words, it is about creating life and work enhancing user experiences through the design, development, construction and implementation of interactive products, devices, systems and services.

Today, interactive products are typically computer-based. This means that interaction design is relevant within all disciplines, fields and approaches that concern themselves with research and design of computer-based systems for people. Hence, alongside design practices such as graphic and industrial design, academic disciplines such as psychology and sociology, and multi/interdisciplinary fields such as human-computer interaction and information systems, interaction design also involves the technical academic disciplines of computer science and engineering. However, interaction design differs from each of these practices, disciplines and fields by having a different, overall, focus and purpose. It is concerned with the *totality* of the user experience of interactive products and with all of the factors that may contribute to their successful creation. When we design computer-based interactive systems, we are not just designing how it appears but also how it behaves. We are designing how people and technology interact (Moggridge 2007). As described by Winograd (1997), doing interaction design can in many ways be compared to doing architecture. The architect is concerned with people and their interactions within the building being created. For example, does the space

fit the lives or work styles of the family or business that is going to inhabit it? Does the flow within and between rooms work well? Are functionally related spaces in close proximity? And so on. Supporting the work of the architect, engineers are concerned with the structural soundness and construction methods of the building, and knowledge from other disciplines, such as human factors and social sciences may also influence the architect's ability to create functional and liveable spaces. Just like a good architect understands these other relevant disciplines, so does a good interaction designer. However, just like there is a difference between designing and building a house there is also a difference between designing an interactive product and engineering its software (Sharp et al. 2007 p. 9).

This analogy also illustrates how interaction design differs from the fields of human-computer interaction and human factors. Whereas HCI and HF have traditionally focussed on the relatively narrow study of human-machine interaction and the major factors surrounding this in order to optimize user interfaces and overall system performance, interaction design is "about shaping our everyday life through digital artefacts – for work, for play, and for entertainment" (Smith 2007 p. xi). In this way, interaction design "has cast its net much wider, being concerned with the theory, research, and practice of designing user experiences for all manner of technologies, systems and products" (Sharp et al. 2007 p. 10). The goal, and the challenge, of interaction design is to make powerful computing technology fit into the peoples' work and private lives rather than forcing peoples' lives to fit technology. In order to achieve this goal, solutions produced by interaction designers must be appropriate to their context (Smith 2007).

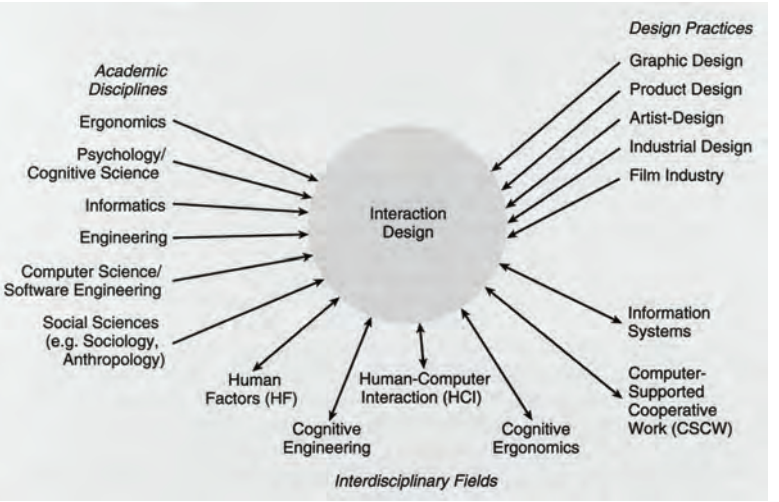

Figure 11. Academic disciplines, design practices and research fields concerned with Interaction Design (Sharp et al. 2007 p. 10).

There is a difference between interaction design *practice* and interaction design *research*. Interaction design practice is about creating concrete interactive systems and solutions to a particular design problem by applying the knowledge and approaches of the discipline. Interaction design research is about creating and improving this knowledge and these approaches, which is often done through studies of interaction design practice. Hence,

it can be argued that interaction design is merely a practice and that it is based on the cumulative sum of research in all of its contributing disciplines and research fields, such as human-computer interaction, industrial design, psychology, sociology, computer science, etc. as depicted in figure 11 (Sharp et al. 2007 p. 10). The risk of such a view, however, is that it presents interaction design as a research-less discipline and distributes interaction design research on a large number of individual disciplines relevant for, but external to, interaction design itself. Thinking about disciplinary borders, which I will return to later, this view essentially keeps interaction design within the confinements of multidisciplinarity without enabling the potentials of cross-disciplinary collaboration in the creation of new types of knowledge and methodological approaches. The opposite view, which I share and promote in this thesis, is that interaction design is, or rather *should be,* a discipline not only with its own practice, but also with its own research agenda and challenges, and that interaction design practice and research are both inherently interdisciplinary.

There is also a difference between being an interaction designer and being an interaction design researcher. Not all interaction designers are skilled researchers, and not all interaction design researchers work as interaction designers. However, given the fundamentally creative and design-oriented nature of the discipline of interaction design, it is my fundamental and strong belief that being a good interaction design researcher requires skills and talents as an interaction designer too.

Mobile interaction design

Mobile interaction design is an area of interaction design that is concerned specifically with the creation of user experiences with interactive products, devices, systems and services that are not stationary but that people can take with them. It is enabled by advances in mobile computing – as described earlier – that have allowed designers and system developers to conceive interactive products that are small enough to be carried with us, held in our hands, or even worn, while also providing computational power and network capabilities sufficient enough for enabling useful and attractive interactive systems and services. This includes handheld and wearable devices, PDAs, mobile phones, smart phones, portable digital media players, handheld games, etc. as well as the software applications and services that run on these devices or can be accessed from them. However, mobile interaction design is not only facilitated and driven by advances in computer science and engineering. It is also increasingly advanced by our ability to develop new use practices for mobile computing and to include and appropriate available and emerging mobile computer and network technologies into new and innovative interactive products and solutions. Hence, we have long gone beyond the "anytime anywhere" mobile computing hype of the late 1990s and grown much more sensible aspirations to develop "mobiles that work at the right time, and that know their place – that fit in" (Jones and Marsden 2006).

The challenges of mobile interaction design have changed and evolved over time as new technologies were developed and new use practices emerged. Early mobile interaction design dealt with the physical design of portable computers. This evolved into a focus on input devices and interaction styles suitable for handheld operation and mobile use. For mobile phones the interaction design challenge has primarily been a

matter of reducing physical size while optimizing the use of limited display real estate and the standard 12-key numeric keypad for more and more possible applications. With the emergence of functionally hybrid and more complex devices, the interaction design challenge became about developing new forms and shapes of devices as well as developing new types of applications available on them, without making the devices (even) harder to use. For the growing range of functionally dedicated mobile devices like digital cameras and media players the interaction design challenge became about facilitating peoples' "orchestration" of all these devices, and their content, in increasingly complex ecosystems of interactive computer systems and digital data.

Today, the challenge of designing mobile interactions is very much about the development of *software applications*. The physical device form factor appears to have stabilized, for some time at least, on the basic size, shape and interaction capability introduced by the Apple iPhone in 2007, which has remained unchanged for more than five years and been replicated by all major handset producers. This has shifted focus towards downloadable and purchasable third party application content available for these devices, in the form of relatively small "Apps" with highly specialised functionality, designed not only by large software corporations but also by small companies and even individuals, including students. By early 2011 more than 500.000 third party applications were available from the Apple App Store and more than 450.000 were available from Google's Android Market. In less than four years more than 25 billion Apps were downloaded for the iPhone and iPod Touch, with another 10 billion downloaded for Android. These are staggering numbers. However, although a lot of interesting and innovative new mobile applications are appearing in Google's and Apple's online stores every day, and application developers and interaction designers world wide are pushing the boundaries of what mobile computer devices are being used for, the state of current mobile application design can be compared to the state of the web in the mid 1990s[2]. There is a lot of excitement and interest, the development tools are easily accessible, and there is a huge audience of potential users. Exceeding the potentials of the web in the mid 1990s there are even well established digital supply chains and mechanisms for micro-payments. But as with the web 15 years ago, I dont think we have yet seen or understood the significance and scope of the impact that third party application design for mobile devices will have on all aspects of our lives, for work as well as for leisure.

Research impact on practice

Much of the future impact of mobile computing envisioned above will be driven by skilful and creative design of mobile interactions conceived by entrepreneurial developers and designers who understand how to create useful and enjoyable utility and user experience that fits the users needs, desires and contexts of use. Unfortunately, however, the current research-based literature on mobile interaction design does not provide as much foundation as we probably could for these developers and designers to base their innovations and interaction design on, nor much methodological guidance on how

2) In 2006, Jones and Marsden (2006) described the state of mobile application design as being comparable to the state of the web in the early 1990s. With the release of the Apple iPhone and App Store, mobile application design took a huge leap forward, comparable in significance and scope to the effects of the first Netscape Navigator web browser in 1994.

to approach the process. Whereas there are a lot of research-based books about user interface and interaction design for desktop applications and web sites there is not yet a lot of equivalent literature available about mobile interaction design. Although mobile computing has a history of approximately three decades, and interaction design has played an important role throughout about 2/3 of this history, only one good general textbook, by Matt Jones and Gary Marsden (2006), has been published on the topic to date. And although this book is indeed a good starting point for addressing the particular challenges of *mobile* interaction design, it still doesn't have the completeness and depth of equivalent human-computer interaction and interaction design primers such as Laurel (1990), Shneiderman (1998), Preece et al. (1994), Winograd (1996), Raskin (2000), Dix et al. (2004) Benyon et al. (2005) Lauesen (2005), Bagnara and Smith (2006), Preece et al. (2002), and Rogers et al. (2011). This is potentially an opportunity missed for large-scale real-world impact on mobile interaction design *practice* in respect to the massive amount of good interaction design research that has been done within the field over the last decade and a half. While it might indicate that the area of mobile interaction design still hasn't stabilized enough for general guidelines, principles, methods and techniques to evolve, it also demonstrates an opportunity, and a need, to push forward on developing such foundational work further.

Several of the textbooks that *do* exist on aspects of interaction design for mobile devices, systems and services, such as Helal et al. (1998), Weiss (2002) Ballard (2007), Fling (2009) and Frederick and Lal (2010), essentially target application development for particular and very specific classes of devices and software platforms, and address ephemeral technical limitations such as particular operating systems, low screen resolution, reduced processing power, limited memory and poor bandwidth. While unarguably useful when designing for these exact platforms, the weakness of such types of works is that they are almost *too* practical. They are highly vulnerable to technological advances and therefore quickly rendered irrelevant as new devices and platforms emerge. As a consequence they usually end up as short-lived and overly specific user interface guidelines tied to a specific point in time, and not as generally applicable and timeless principles for interaction design. Distilling the essence of these works – the higher-level challenges and solutions that apply beyond specific devices and platforms – would be useful for moving the field of mobile interaction design forward. But such work has not yet been done systematically and in depth.

As a step in the right direction though, a different class of textbooks on mobile interaction design is the collection of case study-like accounts for successful and influential design solutions, such as Eric Bergman's "Information Appliances and Beyond" (2000), Lindholm et al.'s "Mobile Usability: how Nokia changed the face of the mobile phone" (2003), parts of Bill Moggridge's "Designing Interactions" (2007), and Bondo et al's "iPhone User Interface Design Projects" (2009). These writings aim to capture universally important lessons learned from the experience of actual mobile interaction designers. They provide interaction design as well as methodological insight about influential solutions and how they came about. The potential weakness of *these* works, however, is that they easily end up being anecdotal and difficult to transfer into present time's design challenges. To support such transfer and transcendence of

knowledge, we must provide not only the case study accounts, but also analysis across these case studies that elevates our learning from the concrete and specific level to the abstract and general. This accumulation of an abstract and general body of knowledge is probably better suited for a design researcher than for a design practitioner, and it is what the work presented in this thesis aspires to contribute to.

Multi- and interdisciplinarity

Interaction design, whether it is mobile or not mobile, is a field of research that involves several disciplines and works across disciplinary boundaries (Sharp et al. 2007 p10). It is widely accepted that research across disciplines is difficult, and consequently, in practice, a lot of such research "actually works at the level of being *multidisciplinary* (or pluridisciplinary): where a group of researchers from different disciplines cooperate by working together on the same problem towards a common goal, but continue to do so using theories, tools, and methods from their own discipline and occasionally using the output from each other's work" (Rogers et al. 2005). Today, mobile interaction design is an example of such a *multidisciplinary* area. This means that it involves a mixture of disciplines, such as computer science, engineering, human factors, psychology, sociology, design, etc. and that these disciplines each contribute to a composite body of knowledge about the design of mobile interactions. Being multidisciplinary means that the challenges of mobile interaction design are approached from different perspectives and with different competences, and that research is therefore diversified and broad. This ensures outcomes that span widely, from new technological endeavours to exploration of new use domains. However, the problem of being multidisciplinary is, by definition, that each discipline retains its own identity, methodologies, assumptions and aims, and that these are not changed or influenced by the other disciplines within the multidisciplinary relationship. Although multidisciplinary research involves several disciplines "each discipline makes as separate contribution" (Moore and Lottridge 2010). This non-integrative mixture of disciplines basically means that there is a shared interest in the topic of mobile computing from within multiple disciplines, but that each of these disciplines treats the common topic of interest in their own way and with their own focus, as defined and guided by their individual school of thought.

The idea of mobile interaction design has appeared in different disciplines at around the same time, but cooperation between these multiple disciplines is largely "mutual and cumulative but not interactive" (Augsburg 2005: 56). This underlying separation between disciplines can be seen in the general observation that although the field is concerned with the same overall topic of *interaction* between people and technology, most specific research is in fact focussed primarily on one or the other. It is either technology- or user-centred, and as pointed out by Rasmussen (2007) when making such clear-cut distinction between technology- or user-centred approaches, a valuable dialectic between the two tends to disappear at the cost of possible synthesis of the two opposing interests and forces at a higher level (Nonaka and Toyama 2002, Dahlbom and Mathiassen 1993). As we observed in an empirical study comparing these two disciplinarily different approaches to the development of two similar interactive mobile systems (Kjeldskov and Howard 2004/chapter 7, Jones and Marsden 2006 pp. 88-89) applying either view in isolation has a notable negative impact on the quality and

completeness of the produced outcomes. Producing well functioning and usable mobile interaction design would be supported better by explicitly combining and integrating technology- and user-centred approaches.

In contrast to multidisciplinarity, *interdisciplinarity* crosses the traditional boundaries between disciplines or schools of thought as new challenges, needs and professions emerge, and blends the involved disciplines including their identities, methodologies, assumptions and aims. It *connects* and *integrates* several academic schools of thought or professions in the pursuit of a common task, along with their specific standpoints, and is not just different disciplines pasted together but rather an "integration and synthesis of ideas and methods" (Moore and Lottridge 2010). On the basis of this, interdisciplinary research derives "novel concepts, methods and theoretical frameworks through the melding of concepts, methods and theoretical frameworks coming from different disciplines" (Rogers et al. 2005). Interdisciplinary research areas often emerge from mutual beliefs that traditional disciplines are insufficient for addressing an important topic on their own, or in a simple non-integrative mixture with each other, due to the topic's multi-faceted, or even transdisciplinary, nature where a unity of knowledge is needed across disciplines, or even beyond them. Where multidisciplinarity approaches a problem space using a *coordinated* effort from *distinct* methodological foundations, interdisciplinarity approaches a problem space using an *integrated* effort from *combined* methodological foundations (Blevis and Stolterman 2009). Hence, the main difference between multi- and interdisciplinarity lies in the way research is conducted, and as a consequence of this also in the types of outcomes produced.

The position that I put forward here is that in order to better inform the creation of interactive mobile devices, systems and services in the future, mobile interaction design needs to evolve from being a multidisciplinary research field to becoming an interdisciplinary one. This position echoes the message from Steve Jobs since early 2010 that the key to Apple's position in the "post-PC era" of interactive mobile systems and devices such as the iPhone and iPad is credited to the explicit belief at Apple that technology alone is not enough, but that "it's technology married with liberal arts, married with the humanities, that yields us the result that makes our hearts sing" (Jobs 2011). According to Jobs, this explicit interdisciplinarity sits "at the intersection between technology and liberal arts", where technical sciences facilitate the creation of "extremely advanced products from a technology point of view" (Jobs 2010) and contemporary liberal art disciplines, such as literature, philosophy, history, science, and design facilitate making them "intuitive, easy to use, fun to use, so that they really fit the users - the users don't have to come to them, they come to the user". This interdisciplinarity is what drives Apple's ability to develop new mobile interaction design that repeatedly pushes the boundary of what is technically possible and, at the same time, is almost immediately embraced globally and soon taken for granted by millions of people.

As pointed out by Rogers et al. (2005) it is not problematic to use the terms multi- and inter-disciplinarity interchangeably if simply referring to collaboration between people from different disciplines working on a common problem. However, depending on the underlying rationale for the collaborative activity, the two can have rather different meanings. Put simply, "bringing together a group of experts from different

disciplines or professions to contribute to a single project, which would not be able to be accomplished by any one profession alone" is different from when "a group of researchers from distinct disciplines try to generate novel concepts and integrate different levels of explanation" (Rogers et al. 2005). Here, the former denotes multidisciplinarity where each researcher contributes to the project with unique expertise, whereas the latter denotes interdisciplinarity where new research questions are dealt with. Achieving interdisciplinarity can be very difficult. Whereas multidisciplinarity can be done through coordination of research efforts, there are many more obstacles to the "cross-fertilization" of ideas required in interdisciplinarity, including incommensurability of concepts, dissimilar units of analysis, variation in world view, etc. (Rogers et al. 2005). This raises the fundamental question of when interdisciplinarity is needed and, and how it then can be achieved in practice.

Basically, interdisciplinarity is desirable when reaching a point where the constraints of ones own discipline prevents any further significant progress, and researchers are forced to work in the outer periphery of their field and, in doing so, are having to forge new ones (The Royal Society 1996). According to Rogers et al. (2005) there are two types of impetus leading to such circumstances motivating input from several disciplines: cases where "an existing problem has simply become too large for a single discipline to cope with", and cases where "something external to the disciplines has forced itself on their attention". Good examples of these two types of cases are the attempt to develop a comprehensive cognitive science program, which held interdisciplinarity as an ideal, and the evolution of the fields of HCI and CSCW, where applied interdisciplinarity was motivated by technological advances within computing. However, for both two cases the project of forging interdisciplinarity faced significant challenges, and it can be questioned how successful the endeavors were. For cognitive science, a major limitation was that the key issues of the "interdiscipline" could still meaningfully, and sometimes advantageously, be studied within a single existing discipline (cf. Norman 1990). For HCI and CSCW a major limitation has been to break away from the multidisciplinary mindset of simply dividing up the joint challenge into coordinated applied disciplinarity, and to really tie together and make mappings across concepts from different disciplines towards the development of unified theory (Bannon 1992). Hence according to Rogers et al. (2005) "the jury is still out as to whether either HCI or CSCW have in fact been able to achieve any significant level of interdisciplinarity".

Modifying the unit of analysis

Mobile interaction design shares properties with both cases above. As with HCI and CSCW applied interdisciplinarity is motivated by technological advances, and as with cognitive science the ideal of interdisciplinarity is motivated by the fact that the full scope of the field is impossible to grasp from one perspective alone. But how can we then avoid repeating the modest success of interdisciplinarity within these related fields? According to Rogers et al. (2005) a possible key to achieving interdisciplinarity lies in explicitly transcending beyond current disciplinary dogma and units of analysis. "If true interdisciplinarity is ever to take off, then what is needed is a paradigm shift whereby a whole set of new issues and research questions are framed that force new ways of conceptualizing and working" (Rogers et al. 2005). This facilitates what they

call "reconceptualizing the domain of interest through using a modified unit of analysis" whereby the scope can be broadened while still allowing the use of existing concepts and theory. As an example, the distributed cognition approach (Hutchins 1995) extended established cognitive science's focus on properties and processes inside a single person's mind to a system of cognitive systems involving several actors and their environment studied through "cognitive ethnography". Although such broadening of scope and change in level of abstraction is difficult and precarious, the benefit is that it has the potential to reveal phenomena that go across, and cannot be reduced to, existing units of analysis.

In relation to Bannon's (1992) concern that the goal of developing interdisciplinary unified theory within HCI and CSCW is fundamentally flawed due to the inherent incommensurability of theory, concepts, traditions, perspectives etc., the significance of the more modest approach of changing the unit of analysis is that theoretical developments from such endeavours can advance our understanding of the field of interest through extending, adapting and integrating *existing concepts and theories.* This can be seen as advantageous over creating completely new concepts and theories, which entail a risk of unintentionally disregarding legacy of previous accomplishments and achievements within the individual contributing disciplines, and potentially separating from valuable epistemological and methodological inheritance.

Classifying research as either multi- or interdisciplinary can sometimes be overly simplistic, as in reality there is a continuum between the two, "from multidisciplinary work with sharp boundaries between the disciplines at one end to the holistic approach of interdisciplinarity at the other" (The Royal Society 1996). This also means that going straight to complete holistic interdisciplinarity is usually not possible but requires evolution through several stages of involved disciplines becoming increasingly integrated as the shared problem is explored, developed and defined. Redefining the unit of analysis can be seen as a way of stimulating such stepwise evolution towards interdisciplinarity by taking its offset in the knowledge and methodologies of existing disciplines, and aiming at developing better understanding of broader phenomena that are, in essence, new to all of those disciplines, and therefore also suitably peripheral to established belief systems.

In order to support the research field of mobile interaction design evolving from being a multidisciplinary area of research to becoming an interdisciplinary one, a change in the basic unit of analysis towards one with a wider scope that transcends the individual contributing disciplines' focus on either users or technologies may be called for. Similarly to Hutchins' (1995) broadening of scope towards "cognition in the wild", a good candidate for such modified unit of analysis, I argue, is the broader and more holistic phenomena of *form-context convergence*. Supporting this position, I am going to briefly turn my attention towards the role of context in the design of mobile interactions.

The role of context

Since the early days of mobile computing and mobile human-computer interaction, the use contexts of interactive mobile systems and devices have often been highlighted as being particularly important for system developers to "be aware of" and "take into

account" when designing and building interactive mobile systems, and when evaluating and studying their use (cf. Johnson 1998, Rodden et al. 1998, Brown et al. 2000). Mobile use contexts have been described as being particularly challenging compared to, for example, the use contexts of traditional stationary office systems due to their highly dynamic, complex, and indeed mobile, nature. It has also often been suggested that when using an interactive mobile computer system, other activities in the surrounding context are often more important than the actual interaction with and use of the system itself – walking down the street, socialising in a bar or café, or attending to a patient in a hospital.

There are many different definitions of context, and the debate on what constitutes context for mobile computing, and what role it plays, is ongoing. Early works within mobile computing referred to context as primarily the location of people and objects (Schilit and Theimer 1994). In more recent works, context has been extended to include a broader collection of factors such as physical and social aspects of an environment (McCullough 2004, Dourish 2004, Bradley and Dunlop 2002, Agre 2001, Dey 2001, Abowd and Mynatt 2000, Schmidt et al. 1999a, Crabtree and Rhodes 1998). Dey (2001) characterizes context as "any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves." Although this definition is quite complete, it is not very specific about what type of information could in fact be used to characterize such a situation. In contrast to this, Schmidt et al. (1999a) present a model of context with two distinct categories: human factors and physical environment. Human factors consist of the three categories: information about the user (profile, emotional state, etc), the user's social environment (presence of other people, group dynamics, etc), and the user's tasks (current activity, goals etc.). Physical environment consist of the three categories: location (absolute and relative position, etc.), infrastructure (computational resources, etc.), and physical conditions (noise, light, etc.). This model provides a good catalogue of specific contextual factors to complement broader definitions like the one by Dey (2001). Other works are not as comprehensive in their coverage of different contextual factors but go into detail about one or a few. In the works of Agre (2001) and McCullough (2004) particular importance is given to physical context consisting of architectural structures and elements of the built environment, for example, landmarks and pathways. In the works of Dourish (2001b, 2004) particular importance is given to social context including interaction with, and the behaviour of, people in an environment. Dourish (2004) also states that context cannot be defined as a stable description of a setting, but instead arises from, and is sustained by, the activities of people. Hence it is continually being renegotiated and redefined in the course of action. These works provide us with additional contextual factors of particular relevance to mobile computing in context, and with the knowledge that what defines context is in itself contextually dependent.

The purpose here is not to challenge these existing definitions of context proposed in the literature. Instead, I subscribe to the definition by Dey (2001) and to the fact that several dimensions of context exist, and that the relevance of each of these for a particular interactive system or use situation is itself dependent on the specific situation.

What *is* important here is the role that "context" can potentially play as a suitable central and mediating concept, or boundary object (Star and Griesemer 1989), in a holistic and interdisciplinary approach to designing mobile interactions. The context of mobile computing is something that several individual disciplines within mobile interaction design are concerned with, and that has influenced the shaping of methodology, technology and theory within and across the field's internal disciplinary boundaries. These different disciplines have each approached the challenge of contexts differently, and have yielded different types of responses.

In domain studies of mobile computing, where context plays an obvious central role as essentially the phenomenon under scrutiny, the challenge has been partly to understand theoretically what use contexts are and how they can be described, and partly to study empirically what characterizes specific use contexts of interest, and how the phenomenon of context can be studied and analysed in ways that generate such understanding. This has led to a body of theoretical and socio-technical research building largely on methods and theories from sociology, anthropology, and phenomenology (e.g. Luff and Heath 1998, Dourish 2001b, Dourish 2004, Dey 2001, Ling 2001, Perry et al. 2001, Fortunati 2001, Green et al. 2001, Agre 2001, McCullough 2004, Chalmers 2004, Aoki et al. 2009, Kostakos et al. 2009), as well as my own work in chapters 3-6 (Paay and Kjeldskov 2005, Paay and Kjeldskov 2008a, Kjeldskov et al. 2004b, Kjeldskov and Stage 2006).

In systems development and design for mobile computing the challenge of context has primarily been about creating an appropriate fit between systems and context and how this can be supported structurally through new, or modified, systems development and design methods. While relatively very little has been published on this topic, there is an emerging body of methodological research building largely on methods and theories from information systems, software engineering and human-computer interaction (e.g. Sharples et al. 2002, Mikkonen et al. 2002, Hosbond 2005, Paay 2008, de Sá and Carrico 2009, Paay et al. 2009a), as well as my own work in chapters 7-10 (Kjeldskov and Howard 2004, Paay et al. 2009b, Vetere et al. 2005, Kjeldskov and Stage 2012).

In usability evaluation for mobile computing the challenge of context has primarily been to understand its role in relation to the scope, richness and validity of empirical findings and how usability tests can be carried out in contextually realistic settings through use of new or modified methods and techniques. This has led to a growing body of empirical research building largely on methods and theories from usability engineering. These include, for example (Brewster 2002, Betiol et al. 2005, Hagen et al. 2005, Kaikkonen et al. 2005, Nielsen et al. 2006, Rogers et al. 2007, Reichl et al. 2007, Oulasvirta 2009, Oulasvirta and Nyyssonen 2009, de Sá and Carrico 2011), as well as my own contributions in chapters 11-14 (Kjeldskov and Stage 2004, Kjeldskov et al. 2005, Kjeldskov and Skov 2007a, Høegh et al. 2008) and also Kjeldskov et al. (2004a)

In implementation of mobile computing the challenge of context has largely been about capturing, formalizing, and modelling this attribute in computational data models, how to make sense from such models, and how to use them in the construction of *context-aware* systems that are responsive to their surroundings. This has led to an extensive body of technical research building largely on methods and theories from computer science (e.g. Schilit and Theimer 1994, Crabtree and Rhodes 1998, Schmidt et al. 1999a, 1999b,

Cheverst et al. 2000, Dix et al. 2000, Chen and Kotz 2000, Hinckley and Horvitz 2001, Dey 2001, Jameson 2001, Jones et al. 2004, Edwards 2005, Hinckley et al. 2005), as well as my own work in chapters 15-19 (Kjeldskov and Skov 2007b, Kjeldskov and Paay 2005, Kjeldskov and Paay 2006, Kjeldskov et al. 2010, Skov et al. 2012, Kjeldskov et al. 2012a).

In user experience research for mobile computing the challenge of context has been to understand what impact rich and dynamic user contexts have on peoples' experience of using technology, and to describe how this user experience can be improved. This has led to a body of theoretical, conceptual, and design-oriented research building on methods and theories from a wide range of disciplines from sociology and psychology to cognitive science, computer science, human-computer interaction and computer-supported cooperative work. These include, for example (Abowd and Mynatt 2000, Cheverst 2001, Palen et al. 2000, Weilenmann 2001, Bradley and Dunlop 2002, Brown and Randell 2004, Bardram 2009, Little and Briggs 2009, Benford et al. 2009, Karapanos et al. 2009, Lindley et al. 2009, Rowland et al. 2009), as well as my own work in chapters 20-23 (Paay and Kjeldskov 2008b, Kjeldskov and Paay 2010, O'Hara et al. 2011, Murphy et al. 2005).

This is not to say that context is a new phenomena appearing on the research agenda with the emergence of *mobile* computing. Context has indeed been an important concept within human-computer interaction and interaction design since the *second wave* or *paradigm* of HCI (Bødker 2006, Harrison et al. 2007). The first wave of HCI was a mixture of engineering and human factors focussing on optimizing human-machine fit. The second wave was largely based on cognitive science focussing on the simultaneous processing of information in machines and in the human mind, but this also involved a strong focus on the use of interactive computing systems in the context of the workplace. However, as pointed out by Bødker (2006) while there was lot of discussion about the intricate concept of context in second wave HCI, this research achieved little in terms of defining and operationalising it in a way of any real significant value to HCI and interaction design. In the *third* wave, focus has broadened further towards a post PC ubiquitous and pervasive information society where computer technology has spread "from the workplace to our homes and everyday lives and culture" (Bødker 2006). This means that context is now an *elemental* concept that we not only need to *define* well, but also need to *understand* better in terms of its complexity, significance, and influence on peoples' experience of technology in use, in order to inform technology design.

Mobile interaction design is positioned within the second and third waves of HCI. It grew out of the second wave, but the tremendous uptake of mobile computing by the general population subsequently played a contributing factor in the creation, force and velocity of the third wave by enabling some of the completely new potentials and patterns of computing technology use that we are witnessing globally today.

2.3. Design approaches

As I have allured to a number of times in the previous sections, mobile interaction design is, broadly speaking, characterized by two different approaches to design: a user- and a technology-centred one. This duality reflects the field's strong roots in the discipline of human-computer interaction on one side, and computing on the other, and an associated difference in primary interest amongst researchers and designers in *people* or in *systems*.

User-centred design

User-centred design (UCD) is a design philosophy and overall methodological framework for conceiving interactive systems, which can be traced back to Henry Dreyfuss' 1955 book *Designing for People* (Dreyfuss 1955). It is about designing interactive computer systems from the user's point of view emphasising people rather than technology (Norman and Draper 1986), and it does this by discovering unmet user needs and responding to these through design. Traditionally, user-centred design and research follows an iterative cycle that consists of the four central stages of studying, designing, building and evaluating interactive systems (cf. Preece et al. 2002, Sharp et al. 2007, Harper et al. 2008). The strengths of this framework is that it is simple, captures some of the essential components of an interaction design process, and provides an overall structure of how to organize them in relation to each other. Historically, another strength of the model has been that it promotes an iterative "prototyping" approach to systems development rather than a linear "waterfall" approach.

The user-centred design philosophy has several branches of more specific methods and associated philosophical views on people and design, such as Prticipatory Design (PD), Usability Engineering (UE) and Contextual Design (CD). Participatory Design (see, for example, Ehn & Kyng 1987, Bødker 1996, Kensing & Blomberg 1998) has its roots in Scandinavia where it was developed as "Cooperative Design" as a part of several research projects in systems development in collaboration with trade unions dating back to the 1970s and 1980s (see, for example, Bødker et al. 1987, Ehn & Kyng 1991). Participatory Design puts particular emphasis on the active involvement of users, and other stakeholders, in the design process in order to ensure the usefulness of the produced outcomes. This is typically done through an action research process where researchers/designers and users cooperate closely and iteratively, and both gain from the relationship. Participatory Design has a clear underlying political dimension of emancipation and democratization, and can as such be described as one of the more radical human-oriented approaches within user-centred design. Some of the key principles of Participatory Design are that users of technology should be respected as experts in their own domain, and recognized as prime sources of innovation. The design task is approached broadly with focus on people, practices, and technology embedded in specific organizational contexts. As a consequence of this, Participatory Design is heavily field based, with researchers and designers spending significant amounts of time "in the wild" rather than in the lab.

While Participatory Design takes user involvement very seriously and elevates user needs, satisfaction and human well being far beyond anything else, a key critique of this form of user-centred design is that it leads merely to incremental design improvements grounded in current practice rather than to design leaps that can facilitate the formation of new practices. Consequently, and somewhat ironically, from a design perspective Participatory Design could therefore be criticised for being fairly conservative rather than progressive. The essential reason for this is that users are not necessarily good designers. They are experts in their own domains, and possess important knowledge for informing design, but they usually know very little about technology and design, and are not trained in projecting into the future and envisioning new technologies and designs. This, it can be

argued, is better done within the expertise of trained designers or engineers. As described by Jakob Nielsen, "users are not designers, so it is not reasonable to expect them to come up with design ideas from scratch. However, they are very good at reacting to concrete designs they do not like or that will not work in practice" (Nielsen 1993 p. 88-89).

This perspective on the role of users in user-centred design is fundamental to the Usability Engineering approach (see, for example, Nielsen 1993, Preece et al. 1993, Spool et al. 1999, Rosson & Caroll 2001). Usability Engineering emerged as a distinct area of research and practice in the mid- to late 1980s. As indicted by its name, it originates from the more engineering-oriented parts of human-computer interaction with many usability engineering researchers and practitioners having a background in either computer science or a sub-area of psychology such as perception, cognition or human factors. Usability engineering emphasises the making of user interfaces with high usability or user friendliness as defined by, for example, the ISO 9241 standard about the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in a specified context of use. This is done by iterating through phases of user requirements gathering, prototype development and usability evaluation against a set of quality metrics. Evaluation is done either by usability experts through, for example, heuristic inspection (Nielsen & Molich 1990) or by testing systems with users (Rubin 1994). Although field based usability testing has been given some attention, usability engineering is heavily laboratory based, with researchers and practitioners spending most of their time in controlled environments rather than in the wild – even when testing mobile computing devices and applications (see for, example, Weiss 2002).

Although usability engineering implies user involvement, a key criticism of this approach is that it reduces the roles of these users to being informants for requirements and test subjects for designs. Consequently they are typically far removed from the actual design and development process, and only brought in very early in the process, before any design has been done, and/or very late when many design decisions have already been made. Another critique of usability engineering in relation to interaction design is that it focuses too exclusively on one particular quality of a design – its usability – and on assessing and making recommendations about where to improve this, rather than on the broader user experience of the design, in all of its contextual complexity, and facilitating the creation of life- and work-enhancing interaction design matching this context.

In attempt an to overcome some of these limitations, Contextual Design seeks to broaden the perspective of the usability engineering process to explicitly include the context, and to inform design more strongly rather than merely assessing and, sometimes, providing recommendations for redesign. Contextual Design is a specific method within the user-centred design philosophy developed by Beyer and Holtzblatt (1998) that accommodates field studies in system development by combining ethnographic methods for data gathering relevant to a particular product, rationalizing workflows, and designing human-computer interfaces. Although parts of the method can fruitfully be applied to non-work related domains, the contextual design method is in essence about supporting work activities through structured and contextually grounded user-centred design. To put it bluntly, it is not a method of interaction design but a good method for doing user-centred usability engineering. Contextual Design provides a detailed account

for what exactly to do, when and how, in a user-centred design process. It does, however, not provide an overall framework for integrating the different disciplines of interaction design. Although it has a strong component of fieldwork and contextual analysis of work and organizations, it is weaker in terms of supporting design and evaluation. Both of these are approached as activities of usability engineering. Contextual Design also doesn't integrate well the technical aspects of interaction design in working with prototypes and exploring actual technology. On the positive side, one of the absolute strengths of Contextual Design is that it is very solution oriented, which makes it attractive as a methodological foundation in industry and research organizations doing more short term and solution-oriented ICT work.

Technology-driven design

Contrasting the user-centred approach, another overall philosophy is to let *technology* drive the process of design. Technology-driven design is about letting the possibilities of new technologies, or existing ones in new combinations, inform what we design and build. Put on the edge, technology-driven designs are not solutions to problems expressed by users but instead solutions to technical problems looking for possible use. They are propositions envisioned by designers or researchers based on their knowledge of what *can* be done, and not in response to what people or users have asked for. In his provocative and highly debated March 2010 column of the ACM Interactions magazine "Technology First, Needs Last", Donald Norman argues that technology-driven design is invariably responsible for all conceptual breakthroughs in modern history. Grand inventions, such as flush toilets, plumbing, electric lighting, cars, airplanes, and ICT, Norman argues, happen because they have been made possible technologically, and not because people have asked for them or necessarily needed them beforehand. Technologists create new designs *because they can.* Products, applications, use and especially *needs,* evolve slowly afterwards (Norman 2010).

Technology-driven design is inherently a trial-and-error based approach in which new ideas are developed, tested, and then explored further or scrapped. Methodologically this makes it a risky and time consuming approach relying on the team's capabilities of reasoning through intuition, experience, deduction and induction with no guarantee of a useful outcome or solution being produced (Kjeldskov and Graham 2003/chapter 2, Danis and Karat 1995). On the other hand, however, this fundamental reliance on the competence of the researchers and designers strongly facilitates the utilization of the precious source of creativity and innovation that these exact people represent. They are typically experts in their area of technology and therefore able to look beyond the technological horizon that "users" without this insight normally have.

Although not a formally established paradigm (like user-centred design) technology-driven design has always been implicitly present as a fundamental approach within the area of computing. According to van den Ende and Dolfsma (2004) neither the development of digital computers after 1960 nor the convergence of computing and communication technologies after 1990 can be explained by rising demand or newly discovered user needs. Instead it was the development of new technological knowledge that was the enabler of new types of computers such as the PC and new communication applications such as the Internet. Had this knowledge been available earlier, those

technologies would most likely have been developed and adopted then. Hence, just like any other area of technology, computing has partly emerged and evolved through a process of technology-driven design based on an interest to explore what would be technically possible more than what would be useful to do. This is simply an established way of doing research within an emerging area of technology (Kjeldskov 2003). Before we can begin contemplating broader phenomena like use, usability, and user experiences of new technology, this technology simply needs to be available in some concrete and functioning form. Technology-driven design provides this, and should therefore not be ignored as a driver, or enabler, of interaction design. On the contrary one could argue that it is in fact a necessary precondition for user-centred design.

Faced with progress where processing power has increased exponentially for half a century, and networking capability, display technology and input devices also follow a significantly fast paced evolution, Jones and Marsden (2006) argue that it is very hard *not* to let technology drive the development of interactive mobile systems and devices. They argue that while user-centred design approaches stay clear of thinking about technology until the user needs have been identified and described – in order not to be distracted by detailed design consideration – when designing mobile interactions there appear to be advantages in allowing the potentials of technology to play a more central role in the process. This view is shared by Rogers et al. (2002) who argue that looking at technologies themselves can be a valuable source of inspiration for design, and by Danis and Karat (1995) who argue that technology-driven design facilitates a dual goal of advancing technology *as well as* creating new usage benefits, while user-centred design primarily focus only on the latter. In the latest issue of ACM Interactions, the importance of technology-driven research is also addressed by Kritina Höök, arguing that it is time for the CHI community to reconnect with the potentials of emerging technologies and, as in the past, "shape interactions based on a deep, well-cultivated understanding of technological capacities" (Höök 2012).

At the intersection between users and technology

In light of the discussion above, if we choose to see interaction design as a matter of innovating and creating new ways of using technology, one can argue that a central shortcoming of the UCD approach is its strong focus on users. Undoubtedly, hearing such a statement from an HCI research academic is bound to cause some raised eyebrows, but bear with me here. Over the last couple of years it has become more and more evident that some companies, most notably Apple, are able to develop, produce and sell millions of novel interactive computer products with groundbreaking interaction design, high utility and usability, and premium user experiences *without* following a user-centred design approach as prescribed by our primary textbooks. How is this possible? *What is it that those companies do that is missing from the established literature on the topic?* It appears to me that the problem originates in UCD being so good at grounding the interaction design task in *current practice* that it impedes our ability to break free from this and imagine *future practices* that are fundamentally different. User-centred design focuses on discovering unmet user needs, but in successfully doing so these needs are reinforced rather than questioned and challenged.

As a consequence, UCD has a track record of resulting in small incremental improvements rather than in fundamental breakthroughs or radical new inventions (Verganti 2010). As discussed by Norman (2010) such improvements are often highly valuable, and in fact where the most frequent gains come from, *but* this type of value adding is very different from the "success by innovation" that prompted the questions about Apple's success. Contrasting the incremental improvements facilitated by for example UCD, Norman continues to argue that conceptual breakthroughs are driven exclusively by new inventions in technology in response to which user needs arise much later. His examples are many, including the automobile, the airplane, radio, TV, the computer, and, of course, mobile phones. Although I agree with Donald Norman about the shortcomings of UCD raised in his column, I do not agree with the conclusion that we should "leave it to the technologists" to "get the grand ideas running". In fact, Normans own argument of new technology initially failing until someone other than the inventor comes along and envisions new usage, indicates to me that there is something else at play here. Instead, I believe that what we are looking for lies in the middle ground between the two. Between fundamental technology invention and incremental user-centred development, or "at the intersection between technology and liberal arts" (Jobs 2010) as often illustrated by Steve Jobs in the later years (figure 12). What we are looking for is exactly what Norman (2010) does not extract from his own examples: the radical innovation created by *merging new technological possibilities with visions of future practice* – without asking the users what they want, but by making radical proposals about it.

This is precisely what companies like Apple are good at doing. In Apple's innovation process "insights do not move from users to Apple but the other way around. More than Apple listening to us, it's us who listen to Apple" (Verganti 2010). However, these radical proposals are not created by chance or from intuition of a visionary guru but from very precise processes and capabilities (Verganti 2009). They require a solid understanding of both technology and of users – perhaps even understanding users more than they understand themselves – and for the latter some of the techniques used within UCD, such as ethnographic studies, are still valuable. Not "to discover hidden, unmet needs" (Norman 2010) but to deeply understand the context that we are designing for.

Figure 12. Steve Jobs on Apple's success at designing interactive products: "We've always tried to be at the intersection of technology and liberal arts, to be able to get the best of both, to make extremely advanced products from a technology point of view, but also have them be intuitive, easy to use, fun to use, so that they really fit the users – the users don't have to come to them, they come to the user" (Jobs 2010).

3. OPPORTUNITIES FOR MOBILE INTERACTION DESIGN RESEARCH

I am now going to change focus and look at the opportunities for mobile interaction design in the early 2000s that motivated my research in this area.

My own research in interaction design for mobile computers began in 2001. At that time, Mobile HCI and interaction design research was still very much in its infancy as an academic research area. Widely commercially successful devices had only been around for about a decade, and leading conferences had only a few years of history behind them. As a consequence only a small body of knowledge existed about this emerging research topic in terms of methodology, interaction design, and real world use, and no coherent sets of methods and techniques for mobile interaction design had yet been established. Driven by the saturation and increasing technological maturity of mobile devices throughout society, there was, however, a huge interest in the new interaction design possibilities of this fast expanding area of computing. This inspired me to carry out a comprehensive literature survey of mobile interaction design research. The purpose was to provide a snapshot of state-of-the-art and current practices, and through this identify shortcomings and opportunities for future research directions. The literature survey was presented at Mobile HCI in Udine in 2003, the second time this conference ran as a full and independent international event (Kjeldskov and Graham 2003/chapter 2), and contributed strongly to bringing the issue of research methodology on the agenda within mobile interaction design. We reviewed 102 articles published between 2000-02 in the most central outlets of its time and classified them in terms of their research method and purpose, as described in table 1 (inspired by Wynekoop and Conger 1990). This provided a picture of how mobile interaction design research was being done, and for what intent, and brought to attention a number of trends characterizing the field, and a number of hidden assumptions influencing its focus and approach. The distribution of articles on research methods and purpose is illustrated in figure 13 clearly showing two peaks, a number of notable but less frequent groupings, and a large number of gaps.

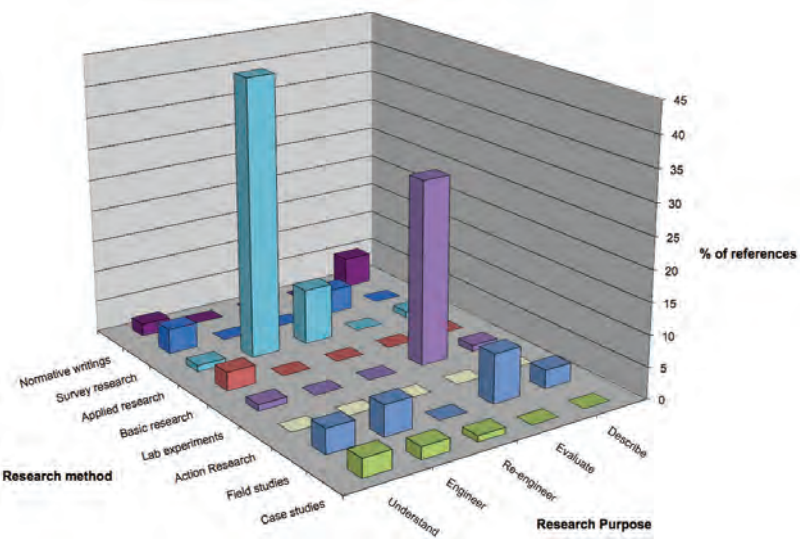

Figure 13. Mobile interaction design research methods and purposes (2000-2002)

Table 1. Overview of research methods and purposes

Method	**Case studies**	Intensive empirical investigations of contemporary phenomena within small size entities such as groups, organizations, individuals, systems or tools in real-life context with the researcher distinct from the phenomena being studied
	Field studies	Characterized by taking place in "the real world" covering a range of qualitative and quantitative approaches from ethnographic studies of phenomena in their social and cultural context to field experiments where independent variables are manipulated
	Action research	A method through which researchers not only add to the body of scientific knowledge but also apply that knowledge to the object of interest through intervention and participation in the activity being studied
	Lab experiments	Characterized by taking place in a controlled environment created for the purpose of research or in dedicated laboratories allowing a detailed focus on specific phenomena of interest with a large degree of experimental control
	Survey research	Informs research gathers large amounts of data through various techniques such as questionnaires and interviews from a known sample of selected respondents assumed to be independent of their environment
	Applied research	Builds on trial and error on the basis of reasoning through intuition, experience, deduction and induction. Typically the desired outcome of an applied research process is known while means of accomplishing it is not. This makes applied research very goal oriented.
	Basic research	Characterized by trial and error based development of new theories and the study of well-known problems to which neither solutions nor methods are known, relying on the competences of the researcher
	Normative writings	Cover the body of "non-research" writings about phenomena of interests such as concept development writings organizing ideas for stimulating future research, presentation of truth describing ideas that seem intuitively correct, and descriptions of applications.
Purpose	**Understanding**	The purpose of research focusing on finding the meaning of studied phenomena through, for example, frameworks or theories developed from collected data.
	Engineering	The purpose of research focused towards developing new systems or parts of systems, for example an interaction technique for a mobile device, or a mobile application or device.
	Re-engineering	The purpose of research focusing on improving existing systems by redeveloping them such as, for example, adapting a web browser to a small display.
	Evaluating	The purpose of research assessing or validating products, theories or methods, for example, the usability or user experience of a specific application, or a theory of interaction.
	Describing	The purpose of research focusing on defining desirable properties of products, for example, an interactive mobile guide system, or mobile interaction design method.

The survey of mobile interaction design research in the early 2000s to a large extend served as a guiding light for my own research in this area in the decade that followed. Not as a collection of ideals or exemplars for what to do and how to do it, but rather as a provocative prompt for exploring their opposites, inspired by Philip Agre's Critical Technical Practice (Agre 1997). But before I outline the specific research topics that my colleagues and I explored in response to the survey, I will briefly describe and discuss some of the trends and assumptions it revealed.

3.1. Trends and assumptions

The literature survey revealed a strong bias towards applied research for engineering and laboratory experiments for evaluation, as shown in figure 13. Put simply, mobile interaction design research in the early 2000s was dominated by building new systems in a trial-and-error manner, and evaluating them in laboratory settings – if evaluating them at all. There was very little going on in terms of trying to understand the phenomenon of

mobility itself in relation to interaction design and technology use, and to use such insight when designing and building actual interactive systems. Nor was much attention given to the role of context in relation to understanding, building or evaluating interactive mobile systems (Kjeldskov and Graham 2003/chapter 2). In essence this echoed a fundamental segregation between use- and technology-centeredness depending on whether the involved researchers were primarily interested in *people* or *systems,* as discused earlier. On a more general level, it became apparent that methodology seemingly played a very small role. The approaches taken often remained unexplained, their suitability unchallenged, and their limitations and alternatives not discussed.

Based on our more detailed analysis of what types of research and purposes were missing, or largely underrepresented, we cautioned that the bias towards trial-and-error building of interactive systems, evaluations only in the lab, and the lack of research for understanding design and use in real world contexts, would limit the quality and scope of the body of knowledge about mobile human-computer interaction being accumulated, and thereby inhibit the advancement and impact of the research field in the future. In particular we found from our analysis that three underlying, and unfortunate, assumptions appeared to be characterizing mobile interaction design research at the time:

1. We already know what to build
2. Context is not important
3. Methodology matters very little

In the following I will briefly take a critical look at these three assumptions and their potential implication for research.

We already know what to build

The prevalent approach of applied research for engineering indicated an assumption at the time that we already knew what systems to build and what problems to solve, such as limited screen real estate, limited means for interaction, and limited network bandwidth. We just didn't know yet exactly how to build these systems and how to solve those problems – but the solutions existed out there and were just waiting to be uncovered. Only very little research addressed the more fundamental questions of what is useful and what is perceived problematic from a user-perspective, and evaluations focused on technical functionality rather than context-centred and user-centred issues. Given the young age of the research field we argued that this assumption could hardly be true and that, on the contrary, young emerging research fields such as this particularly require research addressing such fundamental issues. Continuing to do research on the basis of the assumption that we already know the problem would, in it self, make it very difficult to set this assumption aside and identify the more fundamental challenges at hand.

Context is not important

The limited focus on real-world studies indicated an assumption that context was not really important for what we build, and that interactive mobile computer systems are by definition suitable solutions. Building and evaluating interactive systems on the basis of applied research and laboratory experiments also results in very concrete conclusions

about very specific solutions. These conclusions can be difficult to generalize and therefore it can be difficult to elevate our learning from the systems we develop, and study in use, to an abstract level where knowledge can be transferred to other design cases, technologies, domains, users, purposes, etc. This limits the research field's ability to move forward at a pace beyond incremental steps from one specific design to the next. Hence, in our opinion, the assumption, that building and evaluating systems by trial and error is better than grounding engineering, evaluation and theory in user-based studies, seriously weakened the mobile HCI and interaction design research field at the time.

Methodology matters very little

The observation that only very few studies were based on an explicitly described and considered methodological foundation indicated an assumption that methodology mattered very little in mobile HCI and interaction design research. We presented this supposition as a particularly problematic one because it is well-known that the choice of method influences the results subsequently produced (Myers 1997). Problem solving by applied research is, for example, often viewed as a rather poor method because it demands huge efforts by researchers and often "translates into poor performance because they require search of a large space of possibilities" (Wynekoop and Conger 1990). In relation to mobile interaction design research, a lack of fundamental critical reflection on methodology, and a sensitivity to its importance, would impede our ability to identify the limitations of our work and inhibit the breakthroughs in design and use discovered through deliberately looking at and doing things different than before.

Opportunities

Part of the reason for the bias towards applied research for engineering combined with laboratory experiments for evaluation is that this is a natural place to start when exploring a new field of emerging technology. Before we can study and understand phenomena like use contexts, usability, and user experiences of new technology, we need this technology to be available to us in some concrete and functioning form. However, if a field of *emerging* technology is to evolve into a field of *applied* technology, it is important not to get stuck in research methodologies where solutions are created and put to use by trial-and-error rather than grounded in real world context. Another part of the reason, I believe, is that rather than mobile technologies not being ready for studies in natural settings, the body of mobile HCI researchers at the time were not really ready for natural settings research. In the early 2000s only very few studies had been published that used natural setting research methods within mobile HCI and interaction design. Consequently only very few examples existed for others to be inspired by and follow, and the whole debate about doing research slightly differently had not even started. Adding to this, it was still very unclear exactly how to make use of methods like field studies, case studies, and action research in mobile HCI and interaction design, and what value they might bring to a specific project. Hence, in the early 2000s even the *multi*-disciplinarity of mobile HCI and interaction design was not yet strong. Like other areas of emerging computing technologies it was very much a technical research area dominated by electrical engineering and computer science. In terms of methodology this meant that methods and techniques from, for example, social science, the humanities, and the arts naturally did not yet have a strong presence in the minds and traditions of the dominant

mobile HCI researchers at the time, and prominent researchers from those adjacent fields were not yet working with mobile HCI and interaction design themselves.

Apart from describing and discussing current practice in mobile interaction design research, the survey also outlined a variety of opportunities for doing future research methodologically differently. In particular, the noticeable lack of *field studies* presented an obvious opportunity to use this method for exploring rich real-world technology use cases, contexts and user needs to gain deeper understanding of these. In particular, we suggested to learn more from disciplines that have struggled with the study of similar "slippery" phenomena using techniques such as ethnography. We also proposed that engineering and re-engineering should be informed more by field studies of context and users. Finally, we promoted the opportunity for systematic investigation of field studies for evaluation, as mobility and context can be difficult to emulate in a laboratory.

The lack of *survey* and *case study* research also presented notable opportunities. In the field of information systems, for instance, these approaches are used widely to collect large amounts of data from, for example, a large segment of actual end-users of an interactive system, enabling much greater power of generalization. More case studies within mobile HCI and interaction design could increase learning from existing interactive systems within real-world contexts. This would also enable close scrutiny of specific phenomena in specific settings, which would enrich the collective knowledge in the discipline and enable key issues to be described and understood in depth. The very limited amount of *basic research* indicated an opportunity for the development of theoretical frameworks, and application of existing ones from other disciplines, for describing and understanding mobile interaction design and use. Finally, we argued that the complete absence of *action research* pointed to both the lack of a well-established body of theoretical research within the discipline, and to an unwillingness to roll out mobile systems uncertain to succeed and taking a long time to implement and evaluate. This was perhaps not surprising, given the cost of such technology and the associated implementation overhead at the time. Nonetheless, such studies of practice and intervention was, again, an opportunity to develop new kinds of knowledge in the discipline.

Only a few years after the literature survey, mobile interaction design research had already started to change. The methodological opportunities proposed were indeed taken up by a lot of our colleagues, and today, a decade later, the research field has matured considerably and is making use of a much wider palette of research methods in interesting combinations, and for a much wider range of purposes. This trend was confirmed by a follow-up survey reviewing all research articles concerning the design of mobile interactions published in top outlets in 2009 (Kjeldskov and Paay 2012). From this survey it is apparent that the research field of mobile interaction design has grown substantially in the last decade and is now a substantial part of mainstream HCI and interaction design research. Out of the 246 full and short papers in the Proceedings of the annual ACM Conference on Human Factors in Computing Systems (CHI) that year, almost a fifth concerned human-computer interaction with mobile systems or devices. It is also clear that there has been an increase in the level of empirical research, and that a more diversified set of methodologies for this has evolved. For example, the use

of *field studies* have notably changed and diversified into at least three noteworthy sub categories of *field ethnographies, field experiments,* and *field surveys*.

At the same time, however, there is also clear evidence that the underlying segregation into camps primarily interested in *people* or in *systems* persists. The first aims primarily at understanding mobile user experiences theoretically and conceptually, and the second aims primarily at building new mobile systems and evaluating them in use. This segregation of course stems from the multi-disciplinarity of the research field, but maintaining such a divide sadly sustains the unfortunate implicit assumption that in mobile interaction design research people and technology can, or perhaps even *should*, be studied separately. In turn, such an assumption can be partially responsible for researchers in the people- and technology- oriented camps continuing to investigate the same types of questions and problems as before, rather than defining and exploring new ones in closer collaboration. Within both approaches *users* play an important role, but in the first they are the *objects* of the research, while in the second they are research *subjects*. According to Rasmussen (2007) such clear-cut distinction tends to cause the potentially fruitful dialectics between the two approaches to disappear. If one of the two approaches is considered 100% good and the other 100% bad, from either side of the divide, then one is destined to subsume the other. Dialectic thinking, on the other hand, encourages us to develop a synthesis at a higher stage of the opposing interests, as also discussed by Dahlbom and Mathiassen (1993). This is not simply a matter of finding a balance between the two but about transcending beyond opposing views and shaping a new unity at another level (Nonaka and Toyama 2002). Hence, in order to continue informing the creation of better interactive mobile devices and systems, a closer integration of these two approaches, the user- and the technology-centred one, is still needed.

3.2. Impact on my research

The literature survey described above had a strong impact on my own research in the decade that followed. In particular my colleagues and I attempted to transcend the "people or technology divide" by scoping our work on the design of mobile interactions to be contextual in nature, and aiming to understand the *interplay* between people, technology and context. We did this by working with five particular research topics:

1. Studying and analysing use contexts
2. Using context to inform interaction design
3. Developing new methods for evaluation in context
4. Exploring context-awareness
5. Understanding user experiences in context

These topics are reflected in the five corresponding parts of this thesis.

Studying and analysing use contexts
The first topic addressed the importance of understanding context in mobile interaction design research. Although the literature survey had indicated an assumption that context mattered very little in the field of mobile interaction design, several key researchers had argued for the opposite and stressed the importance of understanding this complex phenomena properly (see, for example, Luff and Heath 1998, Brown et al. 2000, Agre 2001, Dourish 2001b, Greenberg 2001, Perry et al. 2002, Chalmers 2004, Tamminen et al. 2004, Blom et al. 2005). My colleagues and I shared this view, and believed that one of the keys to successful design of mobile interactions lay in understanding, profoundly, what that context is for a particular design task, what dimensions of context are important, what role they play, how they interact and influence each other, etc.? This required empirical and analytical research, prompting us to explore how different aspects of context for mobile interaction design could be studied empirically, analysed conceptually, and presented in a form that could eventually be used to inform design. Our studies of use contexts took the shape of field studies of people, environments, and work activities for the purpose of informing prototype design.

Chapters 3-6 in Part I contain four selected publications from this research.

Using context to inform interaction design
The second topic addressed a methodological gap in terms of how to inform and support the process of designing mobile interactions in a way that was both structured yet supportive of creativity and innovation in design. The ambition of this topic was to move beyond design and development by trial-and-error, and instead introduce some level of methodological guidance for our exploration of new mobile technologies as sought by, for example Krogstie et al. (2004). The literature survey had revealed that mobile interaction design research was very much about building new systems "because it was possible", and although we agreed that a lot of this work was interesting and could possibly be applied to some kind of use, we also believed that this could be done in a much more informed way. However, generally very little had, and still has, been published on this topic. Our view on the matter was that in order to make use of our understanding of context in the exploration of a design space we need to develop ways of transferring empirical and theoretical understanding into the interaction design activity, and develop ways of grounding design ideation and exploration in such input. This required research of creativity that looks in detail at actual processes of interaction design where different methods and techniques have been applied for this purpose. Our studies of such design processes took place as case studies of interaction design projects with the purpose of describing methods, approaches and techniques that worked particularly well – on their own, or in concert.

Chapters 7-10 in Part II contain four selected publications from this research.

Developing new methods for evaluation in context
The third topic responded directly to our suggestion to explore new ways of evaluating mobile interaction design in context as an alternative to the prevailing use of context-deprived laboratory experiments. Already at the first workshop on human-computer interaction for mobile devices in 1998 researchers and practitioners had been

encouraged to investigate further into the criteria, methods, and data collection techniques for usability evaluations of interactive mobile systems (Johnson 1998). By 2002 several studies had confirmed this need (Graham and Carter 1999, Pascoe et al. 2000, Brewster 2002, Rantanen et al. 2002) but methodologically it was still an under-investigated topic. Our position was that in order to realistically assess the quality of mobile interaction designs we need to evaluate them under conditions that are appropriately representative of the future use context. This involves a challenge of trade-offs between factors such as ecological validity, experimental control and data quality, and required empirical research of the applicability and systematic comparisons of the relative strengths and weaknesses of new and existing methods and techniques. Our own work on the topic aimed at systematically investigating the pros and cons of different approaches to empirical evaluation of interactive mobile systems, adapting techniques from ethnography on one side and traditional usability testing on the other, and to learn when, where and how to evaluate interactive mobile systems. The research took its offset in the hypotheses that field studies were a valuable approach because of their ecological validity, but that laboratory experiments could also be improved by simulating aspects of context. On the basis of this, we wanted to explore and refine techniques for evaluating in the field, and to develop and study techniques for recreating contextual factors in the lab. This was done through a combination of laboratory experiments, field studies, and quasi experiments across these settings.

Chapters 11-14 in Part III contain four selected publications from this research.

Exploring context-awareness

The fourth topic embraced the idea of making mobile systems *context-aware* by exploring dynamic use context as means of input in interaction design (Dey 2000). Context-awareness for mobile devices was a relatively new idea at the time (introduced by Schilit and Theimer in 1994) and although there had been quite a bit of work done on the technical side of sensing context, very little had been done on the use of such data in interaction design. Studies like Hinckley et al.'s (2001) use of embedded tilt sensors for automatically changing between portrait and landscape mode, and Cheverst et al.'s (2000) use of location in mobile tourist guides, which are now common features in interactive mobile systems and devices, had only just been published in the research literature, and little knowledge still existed about their actual use. Our position was that in order to inform the creation of contextually informed mobile interaction design solutions, we needed to experiment with functional systems exploring the implementation of design ideas and emerging technologies in practice. This required technical research working with prototypes as vehicles for exploring feasibility, usability, utility, and user experience of various interaction mechanisms, information representations and system architectures.

Chapters 15-19 in Part IV contain five selected publications from this research.

Understanding user experiences in context

The fifth topic grew partly out of the other four and partly out of the lack of basic research for understanding phenomena within mobile interaction design conceptually and theoretically. From the other four research topics we learned a lot about context, how to

design contextually grounded interactive systems, how to make interactive systems adapt to context, and how to evaluate them. However, the insight gained from our studies of technology in use often remained rather specific to the designs that we studied. Looking at related research this seemed to be a general pattern. Only a limited body of knowledge existed that explained, theoretically, the user experience of mobile interaction designs in context. This required theoretical research that developed conceptual understanding of the relationship and interplay between users, technology and their context, and motivated, amongst others, the Indexical Interaction Design project from 2004-06, the eSpective project from 2006-08, and my participation in the Blended Interaction Spaces project from 2008-10.

Chapters 20-23 in Part V contain four selected publications from this research.

3.3. Emerging challenges

Having explored the five topics above, what then are the challenges emerging today? As I described in the introduction, it is my opinion that the enormous uptake of mobile devices, and the role that they have come to play in our lives, means that mobile computing has evolved from being strongly an engineering profession to being, at least, equally strongly a design profession. Hence, interaction design is today of greater importance for the continuing development of mobile computing than ever before, and there is a need to ensure that our overall approaches to the way that we think about and design mobile interactions are up for the challenges that lay ahead. In order to do this I argue that we may benefit from exploring, more profoundly, *designerly ways* of thinking and doing, and from widening our scope, more significantly, to look at the contextual user experience of interactive mobile systems and devices and the digital ecosystems they are forming.

In my view, the first emerging challenge for designing mobile interactions is to *transcend beyond the dichotomy of people- or technology- oriented research and design.* Continuing such divide we are at risk of missing the holistic nature of the mobile interaction design challenges currently at hand, as mobile technologies have matured considerably and now pervade almost every aspect of our lives. What is instead needed is to "reconceptualize the domain of interest through using a modified unit of analysis" (Rogers et al. 2005) – creating a shift in focus where new and shared problems are framed in a way that force new ways of thinking and operating, while still allowing the use of existing concepts and theory. The second emerging challenge is to *widen the scope beyond the individual mobile device and an individual user's interaction with it*. This initial perspective has been researched in depth for over a decade, in both artificial and natural settings, and is now understood quite well. What is *not* understood very well is mobile interaction design within the even larger context, or wholeness, of everyday life and the use of other technologies, that interactive mobile systems have become a part of.

Sections 4 and 5 in this chapter describe my response to these questions.

As I will demonstrate in sections 4 and 5, transcending beyond people and technology, and widening the scope beyond individual devices and users, can both be achieved by changing the fundamental way we think about and go about doing interaction design, from a traditional scientific way towards a designerly way.

4. TOWARDS A DESIGNERLY WAY

I will now shift focus from reviewing past mobile interaction design practice and research to discussing how we can facilitate that these continue to be carried out with significance and impact in the future. In this discussion I will draw on design research literature from outside the field of interaction design, and show how a synthesis of these thoughts and concepts can help enrich the way we think about and design mobile interactions today.

I am going to start by discussing the need for doing, and thinking about, interaction design in *a designerly way* rather than in a traditional scientific way. This is not just a matter of wording or branding, but involves some profound changes to the underlying philosophy, approach, reasoning, and focus in interaction design as a profession and research area. For this purpose I will discuss four different perspectives on design and introduce *contextualism* as an alternative, constructivistic, worldview to the, essentially positivistic, ones still pervading large parts of mobile interaction design today. I will also illustrate how contextual views have informed information systems research, and shaped modern architecture and architectural theory in ways that can enrich our thinking about interaction design. Finally, I will revisit the user-centred design (UCD) approach in light of introduced concepts and perspectives, and elaborate on this model towards a contextual approach focusing on the continual convergence of form and context.

4.1. From technical rationality to continual convergence

While mobile interaction design is a relatively young field of study, *design* has been a recognisable topic of research since the early 1960s. The area of "Design Research" promotes "the study of and research into the process of designing in all its many fields" (Design Research Society 1966), and has had a strong presence within the research area of information systems dating back to the early 1980s. Surprisingly, however, given its seemingly obvious relevance, Design Research has only had very small presence in interaction design – and even less in *mobile* interaction design. Notable exceptions include the work of Rogers (2004), Buxton (2007), Moggridge (2007), and Stolterman (2008).

Design Research has in itself undergone an interesting evolution in philosophy, approach, and focus over the last 50 years, and some of the thinking about design that it has spawned can be used to frame and indicate possible ways forward within the design of mobile interactions. In brief, the origins leading to Design Research can be traced back to early 1920s movements of modern design based on values of objectivity and rationality. The aspiration to "scientize" design re-emerged in post-World War II's increased interest in the use of "systematic methods of problem solving, borrowed from computer techniques and management theory, for assessment of design problems and development of design solutions" (Archer 1965), leading to the "design methods movement" of the 1960's where objectivity and rationality began being applied to processes and not just products (Cross 2001, de Figueiredo and da Cunha 2007). The underlying assumption of instrumental or technical rationality was that design, like science, can be dealt with through decomposition and systematic search through possible solutions. Prominent work within this approach to design included Herbert Simon's "The Sciences of the Artificial" (Simon 1969), introducing concepts such as "bounded rationality", and even the early work of Christopher Alexander (1964), which

had a flavour of rational methodology – although Alexander himself later declared his complete dissociation with this. In the 1970s, however, there was a backlash against the positivistic scientization of design, responding to the seeming inability of technical rationality to "help society achieve its objectives and solve its problems" (Schön 1983), and fuelled by the social and political movements of the time rejecting the conservative values underlying it (Cross 2001). The rejection of technical rationality led to renewed vigour in design research in the early 1980s, seeking the development of design as a discipline with epistemology and foundation in its own history of practice rather than in science. This is largely captured in Donald Schön's "The Reflective Practitioner" (1983), which "explicitly challenged the positivist doctrine underlying much of the design science movement" (Cross 2001) but also partly in Nigel Cross' quest for a "designerly" way of knowing, thinking and acting (Cross 1982).

One of Schön's central messages is that from a technical rationality perspective, professional practice, such as design, is a process of problem *solving,* but that in real world practice problems are not given but need to be constructed. This requires a problem *setting* approach, in which we name what we will attend to and frame its context (Schön 1983 p. 40). In a similar way, Cross argues that there are designerly ways of knowing, thinking and acting, fundamentally different from the generally recognised scientific and scholarly ways, and that these are more about defining the limits of the problem and suggesting the nature of its possible solution, than they are about exhaustive systematic analysis (Cross 1982). This thinking is echoed in a seminal paper by Giovan Lanzara (1983) who outlines three different views on design as 1) functional analysis, 2) problem-solving, and 3) problem-setting, and argues that understanding the underlying views on design can help explain the problems that constrain it. The first two of these correspond to the technical rationality approach while the third corresponds to Schön's concepts of *reflection-in* and *-on action,* and partly Cross's *designerly way* of knowing, thinking and acting. In design as *functional analysis,* design is a process of systematically breaking down the problem through rational analysis and thereby revealing the structure of the one optimal solution. In design as *problem-solving,* design is about finding solutions to problems. In doing this the designer can learn how to structure his search and how to proceed to the next step from the context. The solution only needs to be "satisficing" (Simon 1969), and it is known that it is just one of many possibilities. In design as *problem-setting,* design is a process of collective inquiry and search taking place through transactions and conversations among several actors with mixed interests in the problem at hand. What needs to be created is what the problem solving view takes for granted, and problem representations are not context-free but largely context-sensitive (Lanzara 1983). Design, thereby, becomes a reflective conversation with the materials of the situation (Schön 1992, Winograd 1996 chapter 9).

Design as dealing with emergent goals

Extending on the thoughts of Lanzara (1983) and Schön (1983, 1992), de Figueiredo and da Cunha (2007) and Gasson (2006) discuss a fourth view to represent a contemporary understanding of design processes. In design as *emergent evolutionary learning,* design is the continuous convergence of problem-understanding and solution-proposition through a cyclical process of learning about a situation and responding through design that is

deliberately short-term and partial. This view resonates strongly with Schön's later notion of design as a continual reflective conversation with materials (Schön 1992, Winograd 1996) but emphasises to a larger degree than Schön the dynamic and emergent nature of the *context and goals* of a design and not only of the design itself. The process of design is still rooted in a process of collective inquiry and search, but the notion that structure is inherent in a situation, as assumed in design as problem-solving, is explicitly rejected. Instead, contexts are seen as inherently dynamic and evolving, hence requiring design to be a continuously evolving process too, with an ongoing focus on *both* changing form and changing context. Not only are the problems unclear at the start of the process, so are the *goals* of the design (de Figueiredo and da Cunha 2007). However, as partial solutions are explored, an understanding of the problems, and appropriate design goals, emerges (Gasson 2006).

The view on design as dealing with emergent goals captures, to a large degree, the essence of Christopher Alexander's most recent work on "The Nature of Order" (2002-05). Here, Alexander goes a step beyond the participatory and reflective approach outlined in "A Pattern Language" (Alexander et al. 1977) and "The Timeless Way of Building" (Alexander 1979), and promotes a holistic process of design unfolding where both the context and the form are continuously evolving through a step-by-step morphogenetic process of *wholeness-extending transformations*, that are each intentionally short and open ended. The central contribution of this work of Alexander's in relation to Simon (1969) and Schön (1983) is, in my opinion, that it helps transcend the whole notion of a "problem", and instead makes us focus on the "desiderata", or "that-which-is-desired" (Nelson and Stolterman 2003) in the broader facilitation of human life in all its aspects and richness. Rather than setting and solving problems, Alexander's wholeness-extending design view allows us to treat design as a matter of creating new desired practice, and of dealing with the sometimes ill-defined goals emerging from the design process itself. It may set and solve a problem, but it may also just enable humans to do activities that they couldn't do before – on smaller or larger scales of importance for their life – like streaming a movie or photo from their mobile to their TV, or seeing on their mobile what friends and family on a different continent are up to at the moment. These are interactions that are hard to describe well as "solutions to problems" but easy to describe as meaningful and desirable extensions of a wholeness that was already there.

Alexander's notion of wholeness extending transformations and the view on design as emergent evolutionary learning reflect an evolution of the design discipline over the last three decades, in correspondence with a larger shift in society's world view from one of positivism towards one of constructivism (de Figueiredo and da Cunha 2007, Alvarez and Kilbourne 2002). This evolution of design and shift in world view is of particular interest for contemporary research in the design of mobile interactions because it has parallels with the shift in focus beyond an individual user's interaction with an individual device for a well defined activity, towards the wholeness of mobile technology user experience in indefinable and unbounded activities within the larger, and dynamic, contexts of emergent everyday life.

Looking critically at the predominant design approaches within the area of human-computer interaction, discussed in section 2.3, one could argue that these all fall within Lanzara's three design views, and none of them within the emerging holistic perspective.

User-centred design in the form of usability engineering and Contextual Design are essentially about problem-solving as descried by Lanzara (1983). It is about developing simplified models of the real world, and thereby "bounding" the problem until it becomes sufficiently well-defined to be resolved. Solving the problem is then done by evaluating alternative solutions until one that fulfils a set of criteria is discovered. Hence, design is a rational search process, and solutions are never considered universally optimal, but merely "satisficing" (Simon 1969). The participatory design methodology is different from the usability engineering and Contextual Design approaches to user-centred design in that it particularly addresses the problem-setting aspect of design, or at least aims to do so. Corresponding to Lanzara's (1983) collective inquiry through transactions and conversations among several actors with mixed interests, Participatory Design assumes that there are different perspectives on what the problem is and how it should be solved (Bratteteig 2007), and seeks to uncover these through active involvement of users and other stakeholders in the design process. Hence, design is a reflective conversation with the situation (Schön 1983, 1992), and solutions are unique and appropriate. They are shaped by the shaping of the situation.

Technology-centred design can to some degree be described as functional-analysis in that complexity is reduced by applying scientific reductionism to the (technical) problem at hand. However, in light of Simon's (1969) notions of bounded rationality, rejecting the idea of one rationally optimal solution, it is fairer to describe most technology-centred design as matters of problem-solving. Like usability engineering it is about reducing, or "bounding", the problem by taking ill-structured problems and reducing them into well-structured ones through inductive abstraction, rather than rational decomposition, and then exploring a range of possible solutions essentially through a process of trial-and-error. Unlike usability engineering, however, the initial ill-defined problems are not related to the use of technology, but to the functioning of it.

Design as continual convergence

What is then really missing from the current palette of design methodologies in interaction design is approaches corresponding to the view on design as wholeness-extending (Alexander 2002-05) or emergent evolutionary learning. Such "post–Simon" and "post–Schön" design approaches would take a step further and explicitly subscribe to the view that most activities are unbounded and situated in dynamic contexts, and that the relationship between context and form is therefore a continually changing one requiring that design is inherently cyclic, able to deal with emergent and changing goals, and about construction of context as well as form. They would retain the concepts of "satisficing" design from Simon (1969), though viewed as a much more ephemeral quality, and design as reflection-in-action from Schön (1983), but with added emphasis on designing-through-doing and explicit cyclic exploration of partial solutions as ways of converging requirements and solutions (Alexander 2002-05, Turner 1987). Rather than a rational *scientized* way of interaction design, this would truly be a *designerly* way: rhetorical, exploratory, emergent, opportunistic, abductive, reflective, ambiguous, and risky (Cross 1999). True to its own epistemology and practice, and justified by the efficacy of its results rather than the rigor of its methods (Archer 1992).

Instead of emergent evolutionary learning I will express such a design approach as one of continual convergence of form and context, and claim that apart from also being increasingly problem-setting, rather than merely problem-solving, mobile interaction design should embrace a designerly way of dealing with dynamic contexts and continuously emergent goals and forms. In my use of the term "form", as discussed earlier, like Alexander (1964) I refer to the unity of shape, look, function and content that is formed through design. To extend on the line of thought by Greenbaum and Mathiassen (1990), there is nothing wrong with setting and solving problems when designing mobile interactions. But a focus on the continual convergence of form and context helps shift emphasis towards the larger organic wholes, or digital ecosystems if you will, that interactive mobile systems and services have become a part of.

4.2. World views, root metaphors, and modes of inference

The four views on design as functional analysis, problem-solving, problem-setting, and continual convergence of form and context described above, and the shift from technical rationality to reflective practice, or even artistry, can be further conceptualised and understood by applying the theoretical lens of philosopher Stephen Pepper (1942).

According to Pepper (1942) there are four distinct world views, or root metaphors, through which we can understand the world: *formism, mechanism, organicism,* and *contextualism.* The root metaphor of formism is similarity. Taking a formist view, we seek to understand what the world *is like* by indentifying similarities and differences between things and placing them into meaningful categories. Formist analysis describes either the similarity or differences between two objects, or describes the form that an object exemplifies. The root metaphor of mechanism is the machine. Taking a mechanist view we seek to understand *how things work.* It is assumed that the whole is equal to the sum of the parts, and we try to understand how it works by decomposing complexity into individual parts and looking for cause and effect. Organicism's root metaphor is organic development. The organic perspective is concerned with the coherence between the parts and the whole and tries to understand *how it develops.* Unlike mechanism, organicism does not consider the whole to be simply the sum of the parts, but views the whole as primary and individual parts, only meaningful in relation to this whole. Instability is an inherent characteristic of an organic system. Thus change is given, and it is stability that needs to be explained. Contextualism, as the last of the four, is based on the root metaphor of act-in-context. Taking a contextual view we are concerned with seeing the world in its complexity of context and the need to continuously adapt to its unpredictability and chance happenings, and seek to understand *how this is happening.* The contextual view sees the world not as forms or machines but as ongoing acts that are inseparable from their history, current context, and threads into the future. Like organicism it views the world holistically rather than as a sum of individual parts, but it is more pre-occupied with the active present. Looking across these four world views, formism and mechanism can be described as analytic types of theory (i.e. reductionistic) whereas organicism and contextualism are synthetic (i.e. holistic) types of theory (Pepper 1942). Formism focuses on the concrete, mechanism on laws and principles, organicism on relationships, and contextualism on the contexts in which phenomena occur.

Using Pepper's terms, the shift from viewing design as a matter of functional analysis and problem solving towards a matter of problem setting and continual convergence of form and context is a shift from *formist* and *mechanist* visions of the world to a world view of *organicism* and *contextualism* (de Figueiredo and da Cunha 2007 p. 66). It is a shift from a reductionistic to a holistic paradigm of design, echoing design research thinking subscribing to the view that the process of solving a design problem is identical with the process of understanding its nature. Similar to dealing with "wicked problems", understanding and resolution of a problem are concomitant (Rittel and Webber 1973 p. 161-162) and the designer's ideas for solving a problem influences what information is needed to understand it (de Figueiredo and da Cunha 2007 p. 66). Where formism and mechanism, like science, seek to isolative phenomena from the complex situations they are embedded in and extract generalizable principles (Archer 1992), organicism and contextualism, like design, seek to *embrace* complexity and conceive non-universal and "ultimate particular" results (Stolterman 2008, Nelson and Stolterman 2003), purposely embodying a selection of values determined by their context. Applying organicist or contextualist visions to the activity of design, it becomes a matter of viewing the world holistically, looking at the coherence between parts, seeing it in its complexity, and adapting to its unpredictability. Organic and contextual design are perpetual convergences of solutions and problems – continual convergence of form and context.

Pepper (1942) emphasises that there is a strong tendency to combine contextualist and organicist views, but that there are still some notable differences. Whereas organicism is related to the philosophy of idealism, and explicitly *rejects* reductionism (i.e. formism and mechanism), contextualism is closely related to the philosophy of *pragmatism*, in which positivist principles are accepted, if pragmatically applicable (de Figueiredo and da Cunha 2007). In terms of practice, this means that most non-reductionist design tends to be better characterized as informed by an underlying contextual rather than organicist thinking simply because it typically involves a less rigid – and more pragmatic – view on which principles, techniques, and theories are "allowed" in the design process, as long as it confirms to an overall focus on the contexts in which the design is situated. In pursuit of interdisciplinarity in mobile interaction design, which obviously requires embracing principles, techniques, and theories from other disciplinary areas including ones grounded in positivism, this renders the contextualist (pragmatist) world view most useful.

Design as abductive thinking

When taking a contextual approach to design as proposed here, we also implicitly subscribe to the philosophical worldview of pragmatism, and, at least the essence of, the thoughts of its founding thinkers, such as William James, Charles Sanders Peirce, John Dewey and George Herbert Mead. Pragmatism is a philosophical tradition concerned with the interplay between theory and practice. Of particular interest for design research, Peirce's work on the logic of science explores the issue of idea generation, and promotes a certain mode of inference for explaining this. According to Peirce, new ideas come into being through "logical leaps of the mind", which reflects a third mode of logical reasoning, different from the more conventional forms of deductive and inductive logic. He named this third form of reasoning *abductive* logic. In abductive reasoning, rather than seeking the effect given the cause and rule, or seeking the rule given the

cause and effect, we know the rule and the effect but are looking for the *cause*. Through abductive reasoning we create hypotheses through "inference to the best explanation" (Harman 1965) or guided by our "guessing instinct" (Peirce 1931-58). Peirce came to this viewpoint through a fascination with the origin of new ideas, and the observation that they arose when thinkers encountered data that didn't fit with established models (Martin 2009). The first step in reasoning from here is not observation but *wondering*, and then imagining what could possibly be true. During this process, new ideas emerge as we collect, combine and organise our thoughts in different ways.

Looking at the activity of design *in a designerly way*, as discussed above, it is clear that we are dealing with Peirce's world of abduction: actively seeking new data or signs of effect, challenging accepted explanations or rules, and inferring possible new worlds or causes (Martin 2009). Design *is* abductive (Cross 1999, 2011). It is not about predicting an effect or composing a rule. It is about suggesting possible causes (design) that will create an effect given what we know. Rather than trying to deduct "what is", or induct "why something is", designers are seeking to propose "what might be" (Martin 2009).

As discussed by Martin (2009), a fair critique of abductive thinking in design is, of course, that it does not guarantee success but might possibly lead to poor results – which is why it often scares management and others thinking in a non-designerly way. Therefore, abductive thinking in design should not exclude other forms of reasoning, and should not be used as an alibi for basing everything on intuition and guesswork. But at the same time, as pointed out by Cross, design *is* risky (Cross 1999, 2011), and *not* taking risks in design is more likely a guarantee of failure.

The discussion above is summed up in table 2, outlining the approximate alignments between views on design, interaction design approaches, epistemological positions, ways of thinking and acting, philosophical world views and modes of inference. Table 2 illustrates that contextual interaction design is highly compatible with Schön's notion of reflective design. The key differences lie in the distinction between Lanzara's (1983) category of design as *problem setting* and Alexander's notion of design as *wholeness extending.* This leads to a difference in epistemological position between seeing design as essentially about *thinking*, or about *creation*. The former focuses on the *reflective practice* that happens in design, while the latter focuses on the *continual convergence.*

Table 2. Summary of views on design and associated underlying paradigms and world views.

Design viewed as	Associated with	Interaction Design approach	Epistemological position	Way of thinking and acting	Philosophical world view	Mode of Inference
Functional analysis	Taylor (1947)	Technology-centred	Technical rationality	Scientific and reductionistic	Formism and mechanism	Deductive and inductive
Problem solving	Simon (1969)	Technology-centred User-centred				
Problem setting	Schön (1983)	Participatory	Reflective practice	Designerly and holistic	Contextualism and organicism	Inductive and abductive
Wholeness extending	Alexander (2002-05)	Contextual	Continual convergence			

With these conceptual foundations in place, and the suggestion to take a contextual approach to designing mobile interactions driven by abductive "leaps of the mind" and designerly ways of knowing, thinking and acting, I will now take a brief look at some examples of contextualism in related areas of research and design.

4.3. Contextualism in research and design

The contextual world view has had an explicit presence in the disciplines of information systems and architecture for several decades. In information systems research, Pettigrew (1985, 1987, 1990) has promoted the use of contextualist theory and method for the study of organizational change involving a focus on *content, context* and *process*. Like design, Pettigrew argues that *change* is a phenomenon that is ill-understood in isolation from its context, and that explanations of it are bound to be holistic and multifaceted. Therefore, rather than limiting studies of change to single events or discrete episodes separate from their past, he seek to capture the holistic and dynamic nature of this phenomenon by encouraging research that is contextual in character (Pettigrew 1990). This involves analysis that is both vertical and horizontal – looking at the phenomenon at multiple levels and in perspective of past, present and future time. As exemplified in the work of Mathiassen et al. (2012), Pettigrew's contextualist inquiry framework is a useful approach to the study of change that involves the design of new technology. Framing such study in Pettigrew's terminology, the *content* of change is the transformation from one technology to another (Mathiassen 2012), the *context* of change is the organizational setting on multiple levels including its history, and the *process* of change is the way by which the new technology is developed and deployed. Thinking about this from a design perspective, it is interesting to note that the concepts of context and process are similar, but what is considered the *content* of IT-enabled change in Pettigrew's framework equals, or at least has a large overlap with, what is considered the *form* of interaction design, in Alexander's use of the term. They are both concerned with the introduction of new technology and its influence on people and use – and herein lies exactly the link between a contextual approach to information systems research and a contextual approach to interaction design, as illustrated in figure 14. Applying Pettigrew's (1987) contextualist framework to interaction design emphasises the importance of developing interaction design *processes* or approaches that can inform and stimulate the interplay between form and context. The design of mobile interactions as a continual convergence of form and context is an example of such an approach.

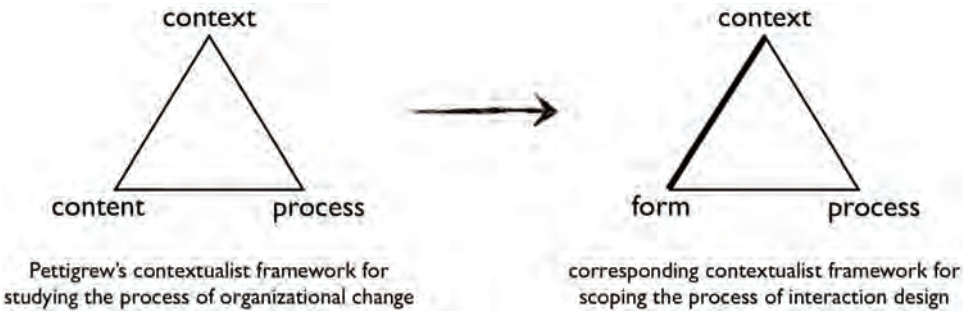

Figure 14. Towards a contextualist framework for interaction design, based on Pettigrew (1987).

Another key insight for interaction design to be drawn from Pettigrew's contextualist framework is the notion of vertical and horizontal analysis. Vertical analysis as an acknowledgement of the contextually multi-layered nature of any design challenge spanning, at least, from detailed human-computer interaction, over user experience, to wider use in context of work or life. Horizontal analysis as a recognition that, like change, design is always situated in a historical context. It has a past, a present and a future, and in doing interaction design we need to have a sensitivity for the fact that new designs do not appear in a vacuum, but almost certainly replace or add to something that was already there. By doing that, design inherently changes its own context and thereby the preconditions for future design.

Contextual architeture

As Schön points out, architecture is "perhaps the oldest recognized design profession and, as such, functions as a prototype for design in other professions. If there is a fundamental process underlying the differences among design professions, it is in architecture that we are most likely to find it" (Schön 1983 p. 77). Some movements within modern architecture particularly emphasize the importance of matching buildings to their surroundings. This design philosophy, known as "contextual architecture" (Brolin 1980, Ray 1980, Shane 1976), has given rise to several highly acclaimed buildings around the world praised by their inhabitants for the way they fit naturally with their surroundings. Apart from having a notable effect on its *outcomes*, working within this design philosophy also has some profound impacts on the *process* of design. Architects working closely with the context of their buildings spend significant amounts of time developing and assessing their design *on the building site* rather than at the drawing board in their studio. As an example, it is a well-known fact that the Danish architect Jørn Utzon, who is probably best known for the Sydney Opera House, spent considerable time on building allotments exploring their contextual properties before and during the development of his building designs. In a rare interview he even described how he would sometimes map out the possible location of walls and windows by placing lines of small rocks on the ground, and then walk around imagining the view of the surrounding environment from these as yet un-built rooms. In an account of the works of Alex Popov (a Sydney-based contextual architect and former associate of Utzon) it is described how the result of buildings created with such sensitivity to the way they engage with their surrounding environment is that they do not just fit their context well, they themselves become part of that evolving context (McGillick and Carlstrom 2002).

In architectural theory, contextual architecture is described as a matter of pursuing the notion of *genius loci* (the protective spirit of a place in classical Roman religion) by responding to the topographical, geographical, social and cultural context of a building site (McGillick and Carlstrom 2002). This concept is most notably explored by Norwegian architect and theorist Christian Norberg-Schulz in his phenomenology of architecture (Norberg-Schulz 1980) arguing that genius loci – or sensitivity to context – has profound implications for place making. Echoing this line of thought, Christopher Alexander argues that architecture exhibiting a quality of "timelessness" always evolves through a series of "wholeness-extending transformations" (Alexander 2007) in which the designer has not only focused on the creation of new form but done this with deep

understanding of and respect for the existing context. Alexander's Pattern Language (Alexander et al. 1977) contains a collection of form-context pairs composed to help evoke the readers' imagination of a future design in context – enabling such wholeness preserving contextual architecture in practice. Such quality of design is also described as "ensoulment" by Nelson and Stolterman (2003 p. 285) who writes that "ensoulment is about wholeness and composition, as well as value and meaning" and that "to ensoul a design – in a way that attracts attention and appreciation – demands a respect for the materials, the structure, the shape and its social dimensions" (i.e. its context).

Over the course of more than four decades of empirical work, Christopher Alexander's view on design has evolved considerably towards a holistic and dynamic perspective of the world, resembling the vertical progression outlined in table 2. From the borderline technical-rationality thinking about the interplay between form and context expressed in "Notes on the Synthesis of Form" (1964), over the participatory and reflective approach outlined in "A Pattern Language" (1977) and "The Timeless Way of Building" (1979), to the continual transformation of wholeness expressed in "The Nature of Order" (2002-05). Using the terms of Pepper (1942), the bulk of this work is an exemplar of contextual thinking – probably even bordering on organicism in its latest propositions. It reflects a designerly way of thinking and acting dominated by abductive reasoning, deals with the setting of the problem and not just its solution, and it emphasises that design is about the continuous construction of wholes that amount to more than the sum of their parts. This makes Alexander's thinking particularly relevant for a contextual perspective on designing mobile interactions because it resonates with the emerging need for a perspective transcending user- or technology- centeredness and capable of informing the design of digital ecosystems and holistic user experiences rather than just single devices, systems and interactions.

The nature of order

Alexander's theory about the nature of order (Alexander 2002-05) is a complex piece of design philosophy. In this thinking, design is a matter of pursuing a quality that creates a deep subjective feeling of connectedness in people in its presence, but that we do not have an established name for. Alexander himself calls this quality "life", "wholeness" or "living structures", and argue that the degree of life in things is an objectively observable quality that can be measured empirically. He also argues that the degree of life in things is correlated with the repeated appearance of fifteen empirically identified properties[3]. These are seen in human-made design with a holistic quality, but also *in natural systems*, which, Alexander speculates, may be why people respond emotionally and cognitively positive to them when encountered in artefacts. The feeling of life in a natural thing or in a design stems from an experience of *its whole* and not simply from the sum of its parts. In fact, according to Alexander, it is the whole that defines the parts and give them meaning, and not the other way around. "The flower is not *made* from petals. The petals are made from their role and position in the flower" (Alexander 2002b p. 87). Instead of individual "parts", wholes may consist of smaller entities, at different scales, each with their own

3) Levels of scale, strong centers, boundaries, alternating repetition, positive space, good shape, local symmetries, deep interlock and ambiguity, contrast, gradients, roughness, echoes, the void, simplicity and inner calm, and not-separateness.

localised quality of wholeness. Such sub-wholes are denoted as "living centres", which can be described as interrelated focal points within the larger whole, each reflecting "an organized zone of space, which because of its internal coherence, and because of its relation to its context, *exhibits centeredness*" (Alexander 2002b p. 84).

The value of the concept of living centers is that it captures the main features that make a difference for our experience of the world, and contributes to its wholeness. In terms of design it thereby becomes a possible means of navigating the challenge of achieving wholeness by providing cues about focal points within it. What is important to notice here, however, is that following the holistic mindset, the centers that make up a given wholeness do not exist independently, but only become centers as a result of the configuration of the whole. Hence, one cannot simply "break down" an overall design challenge into design of individual centers, but have to maintain a simultaneous focus on the whole as well as the parts.

Alexander's perspective on good design as "living" wholes of form and context has some profound implications for the *process* of design. In terms of process, Alexander emphasises that new design with the quality of wholeness or life never just appears out of nowhere but always *evolves* from a previous state of wholeness, which initial qualities it is able to maintain or expand. Methodologically, this is reflected in the principle of "structure-preserving" (Alexander 2002b) or "wholeness-extending" transformations (Alexander 2007), through which living form-context ensembles gradually evolve, or "unfold", over time (figure 15). The unfolding of wholes through wholeness-extending transformations builds on the fundamental view of Alexander's that *future* design wholeness is already *latently present* in current wholeness, and that designing therefore has to be a process of step-by-step adaptation of form and context towards increasing quality and complexity, rather than a matter of defining a desired end-state up front, and then setting out to produce this efficiently and with little or no change. Wholeness and life is, according to Alexander, simply not something that can just be defined or specified and then built. Like generated structures in nature it inherently has to emerge from a growth process of modification and adaptation that happens gradually in response to feedback about "the extent to which an emerging structure supports and embellishes the whole" (Alexander 2002b p. 230). Or as more pragmatically expressed by Moggridge (2007), in design "whatever you come up with will automatically build on the past", and hence "if you are designing a new version of something that already exists, "state-of-the-art" is the most useful starting point" (Moggridge 2007 p. 728).

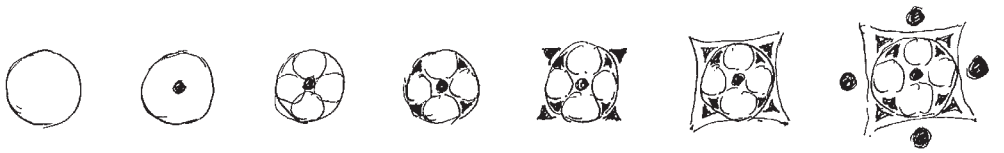

Figure 15. Six wholeness-extending transformations (left to right) (Alexander 2002b p. 52)

While Alexander provides lengthy and detailed discussions about the properties of holistic and living processes and incites a process *"which can support the continuous creation of an emerging living structure in the world"* (Alexander 2002b p. 508), he does not himself present a straightforward operational model or methodology of what such process may look like in practice. Hence, the question remains about how exactly we may procedurally go about achieving wholeness in design?

Overall, Alexander states that the types of processes that are capable of intensifying wholeness are the ones that place more emphasis on the context, and, in doing so, encourage the use of wholeness-extending transformations, and the creation of living centers. He also states that such processes must be "morphogenetic", or "architectural", meaning that they *create coherent form in the world* and explicitly emphasise this form-creating aspect of the process – that is its "designerly" nature, to use Cross's (1982) term. Thirdly, he highlights that in order to create unpredictable (i.e. non-trivial) or unexpected outcomes (Nelson and Stolterman 2003), the design process must be open-ended and itself partly unpredictable in order to truly accommodate for unforeseen adaptation and unfoldings of form and context. According to Alexander, such open-ended, unpredictable, morphogenetic processes, may only be achieved through step-by-step adaptation with appropriate feedback mechanisms for continually assessing the outcome of the process so far, and informing its immediate future direction. *"The process must go gradually, in a way that allows assessments, corrections, and improvements to be made about the degree of life which occurs throughout the structure, at all scales and at all levels. This process must occur continually throughout the conception, design and construction"* (Alexander 2002b p. 237). Hence, the designer needs to be able to shift focus and technique *as needed* whenever in the process – go back to the drawing board, study an aspect of the design in more depth, build and test a prototype, analyse data from a new perspective – instead of being confined to a predefined sequence of activities. A process like this is inherently contextual, iterative and multidirectional. It views the world as inseparable from its history, current context, and threads into the future. It unfolds stepwise but can at any point go in any direction, and it has no predefined starting or ending points.

4.4. Elaborating on user-centred design

In light of these perspectives on design, I will now turn my attention back to the prevailing user-centred design (UCD) approach to interaction design, and respond to some of the shortcomings of this approach discussed in contemporary interaction design research.

As described earlier, user-centred design typically follows a cycle consisting of four stages in which we study, design, build and evaluate technology, as depicted in figure 16. Other labels exist, but essentially they denote the same activities (Harper et al. 2008).

Figure 16. The traditional, four-stage UCD model (Harper et al. 2008)

One of the shortcomings of the UCD model is that it is almost too simplistic and high level. It does not say much about the outcomes from each stage, what they are, and how they differ. It is also unclear how the iterative nature of the model actually works: how different iterations can take different shapes and have different outcomes, and how continuous iteration is cumulative and going forwards towards better outcomes, rather than just going around in a circle. Looking at support for how to iterate through the stages it is also unclear why the activity of "evaluating" is followed by the activity of "studying". If working truly iteratively by designing on the basis of user studies and then evaluating prototype solutions by putting these back in the hands of prospective users, then aren't evaluating and studying in fact two variations of the same type of empirical activity? Finally, it can be questioned if a predefined cyclic sequence really depicts the quintessence of well-functioning interaction design processes, or if such processes are in fact, or ought to be, far more elastic and irregular?

As a response to some of these shortcomings, in the recent Microsoft research report "Being Human: Human-Computer Interaction in the Year 2020" (Harper et al. 2008) it is proposed that the traditional four-stage UCD model is extended with an additional stage in order to better accommodate for "third wave" (Bødker 2006) HCI research that focuses on human values and shaping society's new relationships with emerging ecosystems of computer technologies (figure 17). The additional stage is labelled "understanding" and is placed into the model as an initial activity of conceptual analysis to "focus on human values and to pinpoint those that we wish to design for and to research" (Harper et al. 2008 p. 59). It is a stage meant to involve specifying what kinds of people are the focus of a particular project, and understanding their domains of activity, cultures etc. which will in turn "either point to some fundamental research which needs to be carried out in Stage 2, or will provide guidance toward relevant research which has already been carried out" (Harper et al. 2008 p. 59). While it is noted that understanding a problem is traditionally a part of studying, it is proposed that "it be elevated to become a more explicit process, where the various human values at play are thought through and the trade-offs are examined in a systematic way" (Harper et al. 2008 p. 58).

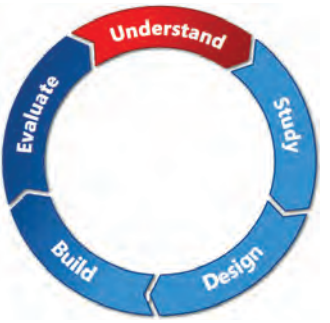

Figure 17. The extended, five-stage UCD model (Harper et al. 2008)

The motivation behind this extended approach to HCI research and design is sound. As we are moving towards the third wave of HCI research, understanding the contextual richness and width of the people, activities, cultures etc. that we are designing for is hugely important. Hence, at first glance, I myself embraced and promoted the inclusion of understanding as an additional step in the UCD model. However, after having thought about it for a while, the proposed five-stage model is, in my opinion, actually a bit problematic and raises more confusion to me than clarity.

One of the problems is that it separates further the already overlapping activities of evaluating and studying with a stage that essentially doesn't fit there. How can you really understand something before you study it? Another problem is that the proposed new stage to "understand" does not type-match the other four stages in the model. Studying, designing, building and evaluating are all *activities* – something you can say to be doing. Understanding is not. It is the *outcome* or *purpose* of an activity. Thereby the proposed extended model now confuses the "how" and the "what" of the process of interaction design. While it might make perfect sense to suggest that the first stage of a design or research project should be to "understand" something, the question that needs to be raised must necessarily be *how* this understanding is obtained? My suggested answer to this is simple: *study and analyse.* If we wish to understand the broader contexts of an interaction design challenge better, which I agree we should, then it is a matter of specifying *what* should be studied and analysed, and *how* it can be done in order to obtain the desired insight.

In response to this, and informed by the discussion of design research, I suggest three alternative changes to the traditional UCD approach:

1. Separating and redefining activities and outcomes
2. Shifting the gravity point away from user-centeredness
3. Making the process flexible and unpredictable

Separating and redefining activities and outcomes

My first suggestion for change is about activities and outcomes. In the alternative modification of the traditional UCD model depicted in figure 18, three key factors are changed. Firstly, the activities and the outcomes are separated. Activities are depicted as arrows in a circle while the outcomes are depicted outside the circle towards the top

or bottom. This explicitly highlights the dual-purpose of interaction design research and practice: it is about creating *understanding* and *artefacts.* Understanding is the result of the activities of studying and analysing, and artefacts (i.e. interactive systems) are the result of the activities of designing and building. Where understanding constitutes the foundation on which artefacts are designed and built, conversely artefacts, whether they are the designer's prototypes or already existing ones in the use context, constitute the foundation on which understanding is created through studying and analysing.

Secondly, the activities of evaluating and studying have been merged into one, reflecting the view that evaluating is in fact a *type* of studying and that differentiating between the two creates an unclear intersection between them when looking at the overall iterative process. Thirdly, the activity of *analysing* has been added as an explicit stage between studying and designing. This reflects the view promoted by Harper et al. (2008) that we do indeed need to elevate the importance of developing theoretical and conceptual understanding of the problem at hand in all of its richness and detail, including issues such as human values, context of use, and user experience. However, contrary to Harper et al.'s (2008) extended UCD model, this is reconceptualised here as an explicit theoretical activity of *analysis* closely related, but subsequent, to the empirical activity of studying. This activity *leads to* understanding.

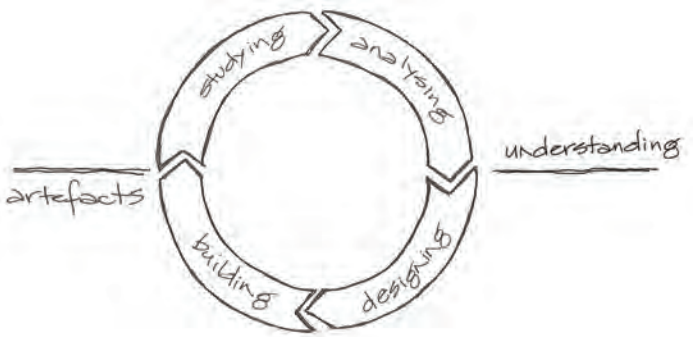

Figure 18. Revised and extended four-stage UCD model. Understanding and artefacts represent the two primary types of outcomes produced during the top and bottom two activities

Shifting the gravity point

My second suggestion for change is about focus. In response to the ongoing debate about UCD being inadequate for informing the creation of novel and innovative interactive systems due to its built-in orbit around *users,* my second suggestion is to change this fundamental point of gravity towards one that better captures the essence of the emergent challenges at hand. In his 2005 Interactions magazine column, "Human-Centred Design Considered Harmful", Donald Norman (2005) already alluded to such fundamental change in gravity point by proposing *Activity*-Centred Design (ACD) as an alternative to UCD. Activity-Centred Design doesn't focus on user goals or preferences but instead more broadly on what they are doing (Saffer 2007). Although this suggestion is a step in the right direction, making "activity" the centre of orbit still doesn't quite suffice - at least not in the case of *mobile* interaction design. In order to better fit the challenges of designing mobile interactions, the gravity point, or unit of analysis, really

needs to be shifted towards one with a wide enough scope to encompass the more extensive phenomena of *contextual user experiences* in a holistic way. Activity is a part of this, but equally so are other factors such as settings, people, artefacts, technologies, time, and more importantly the contextual whole that is made up by all of these. A similar point of view is made by Bill Moggridge (2007) in a critical self-reflection on the scope of the people centred prototyping approach used at IDEO, when he asks: "Is this focus on people and prototypes enough? Can we rely on just those two simple strategies to create excellent designs? I'm afraid not, as the constraints will come from the *full context* of the design problem, *not just the people.* (Moggridge 2007 p. 725, italics added). He continues, "you will need to understand as much as possible about everything that will affect the solution (…) find out as much as [you] can about the *context*" (Moggridge 2007 p. 726, italics added).

In response to this, and echoing Alexander's (2002-05) views on design as a continual interplay between form and context discussed earlier, I suggest that a better point of gravity for mobile interaction design would be *the ensemble, symbiosis, or convergence of form and context.* This is illustrated in figure 19.

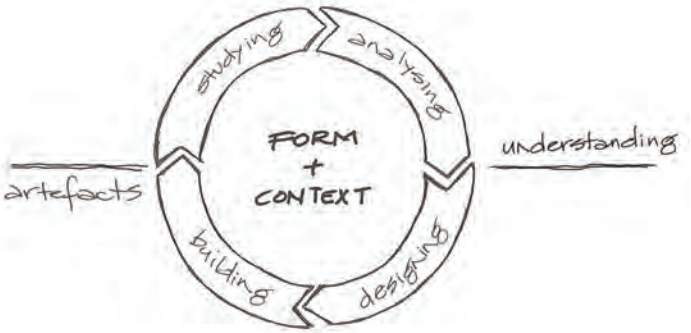

Figure 19. Shifting the gravity point to *form-context* syntheses rather than *users*

Shifting the gravity point of the underlying process model from users to form-context convergence echoes the need for emerging interdisciplinary research fields to change the unit of analysis towards one that transcends the individual contributing disciplines as discussed previously. As discussed in section 3, the methodological foundations and contributing disciplines of mobile interaction design are not yet integrated in an *inter*-disciplinary way, where researchers from distinct disciplines generate novel concepts and integrate different levels of explanation in joint pursuit of a more profound research problem impossible to grasp from one perspective alone. This is evidenced in the observation that current mobile interaction design is predominantly either technology- or user-centred, and hence to a large extent still resonate the classic disciplinary separation between science and engineering on one side, and art and design on the other. In relation to this observation it could be argued that the user-centred design approach, although originally developed to facilitate interdisciplinarity within systems development, in fact works *against* increased disciplinary integration, as much as purely engineering driven systems development, by strongly promoting one particular perspective rather than a holistic one in which technology and users are considered and weighted as equally

important. If interdisciplinarity is to take place within mobile interaction design, this is not a viable course. Instead, what is needed is a paradigmatic shift stimulating new ways of conceptualizing and working by framing new issues, research questions and challenges *beyond* those of the individual disciplines involved. *Form-context convergence* is an interesting candidate for such higher-level unit of analysis.

Using this conceptual optic on the revised approach in figure 19, the activities of studying, analysing, designing and building are all about considering the ensemble of a particular form (an interactive mobile system) in relation to its context (users, technology, settings, activities etc.) from different perspectives, with the purpose of producing either understanding or artefacts depending on whether you are in the top or the bottom part of the circle. Consequently, the interaction design process becomes neither user- nor technology-centred but instead transcends and continuously includes both of these viewpoints within a broader perspective on the contextual whole in which users and technologies interact.

Putting form-context convergence in the centre also respond to the concerns raised by, among others, Rasmussen (2007) that the original intentions of human-centeredness, as envisioned in the 1970s, have in UCD degenerated to being a limited paradigm of creating user friendly computer interfaces rather than focusing on the broader societal issues facing human kind through "socially useful production" and "human machine symbiosis". While some of the thoughts behind human-centeredness can still be still traced in the user-centred design literature, the focus has become predominantly on how people interact with computers rather than on "how the technology can be shaped to support enrichment of human skills and socially useful products" (Rasmussen 2007 p. 475). According to Rasmussen (2007) and Gasson (2003) a similar tendency can also be observed within the discipline of Interaction Design when the discourse starts with the concept of computer-based technology and when designers "ignore the context of design as systems situated in physically and socially constituted environments" (Rasmussen 2007 p. 476). Rather than producing socially and holistically useful products, this results in incremental or "problem-closure" development of products framed by relatively limited tasks in isolation from the social world that surrounds them (Gasson 2003 p. 36). In reaction to this, Rasmussen (2007) proposes a "human-context centred" approach revitalising the original intentions of the human-centred tradition and promoting the fundamental view that "although human beings are important creatures in the world, they are still a part of a much larger context of natural and social relationships, in which they should try to act and interact in a sustainable manner" (Rasmussen 2007 p. 478). At the core of this proposal is the principle of dialectical thinking in order to overcome the weaknesses of differentiating between technology- and user-centred approaches. Rather than making such clean-cut distinction, or finding an optimal balance between the two, a possible *fusion* of the opposing interests and forces is sought by transcending to the higher-level unity of form-context convergence.

Making the process flexible and unpredictable

My third suggestion for change is about process. In light of the view that designerly processes of creation unfold stepwise through unpredictable sequences of assessment, corrections and improvements of form-context ensembles with respect to their larger

whole, my third suggestion is to discard the view that interaction design should follow a predefined cyclical sequence of activities, like the one depicted in the traditional UCD model. Inspired by Alexander (2002-05) I instead propose a web process model that explicitly allows unpredictable, less orderly and more complex sequences of design, allowing the designer to shift focus and techniques as deemed necessary on basis of the continual consideration of outcomes so far. This is illustrated in figure 20.

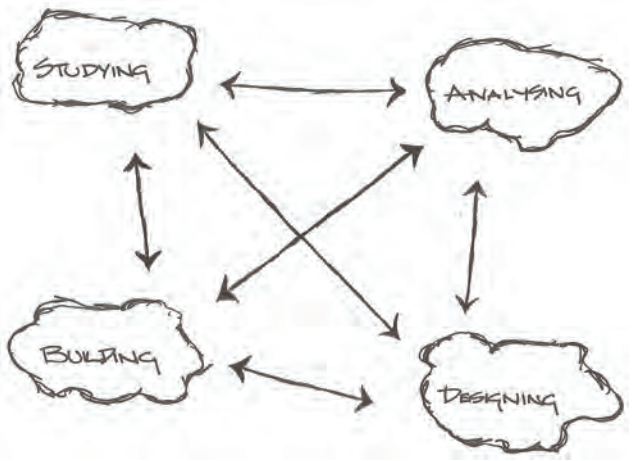

Figure 20. Replacing the predefined cyclical sequence of activities with a flexible web process model that allows unpredictable, less orderly and more complex sequences

The key difference between this and the traditional cyclical UCD approach is that it encourages a much more flexible and pragmatic way of dealing with the design challenge at hand. Rather than being stuck in a particular activity until it is "finished", and then having to wait for a whole iteration before attending to this activity again, a web, or "stepping stone" (Stokholm 2008, 2010), approach allows the designer to jump freely and frequently between activities, thereby responding better to the emergent needs of the process, and letting the evolving form-context symbiosis control the process rather than the other way around. Clockwise circular sequences are of course not prevented, but they only happen when considered appropriate.

By taking a more flexible and unpredictable process like the one depicted in figure 20 as the methodological foundation for design, rather than a predefined cyclic one as prescribed by UCD, one would in fact support what often happens in real world interaction design practice, as described by Bill Moggridge (2007 p. 649-650, p. 729-730). One would recognise that the most successful design processes are usually out of sequence, apparently unstructured, and sometimes almost seem random – like the ball bouncing in unexpected directions inside a pinball machine, to use Moggridge's own analogy – and acknowledge the knowledge amongst experienced designers, that the fastest way to achieve a successful design is to use the tools and techniques of the trade "quickly and repeated frequently, but usually not in the same order" (Moggridge 2007 p. 729).

5. THE CONTINUAL CONVERGENCE OF FORM AND CONTEXT

Having arrived at a higher level of insight into designerly ways of thinking and working, and having used this to respond to shortcomings of the prevailing user-centred approach, what then could an alternative, designerly and contextually oriented, approach to designing mobile interactions look like? In this section I will sum up my position on this based on the discussions and synthesis of thoughts and concepts in section 4.

The view emerging from my research is that as we move towards a society of increasingly widespread pervasive computing and digital ecologies, the design of mobile interactions accordingly needs to transcend existing approaches and develop a holistic and contextual view on technology design. My approach to doing this is to use the ensemble of form and context as our central unit of analysis and embrace a designerly way of achieving convergence between form and context through a *contextually grounded, wholeness sensitive, and continually unfolding process of design*. I describe such an approach to designing mobile interactions as one of *continual convergence of form and context*. This approach describes the dual-purpose unfolding of mobile interaction design research and practice, and ties together *empirical, creative, technical* and *theoretical* types of work and thinking that takes place within the design activities of *studying, analysing, designing* and *building* interactive mobile systems. It is neither user- nor technology-centred, but instead enables and encourages truly interdisciplinary research and design at the intersection between technology and liberal arts by transcending these two viewpoints.

My proposed approach to designing mobile interactions can be characterized and described by the following seven principles:

1. Emergence and unpredictability
2. Form and context unity
3. Form and context convergence
4. Oscillation between understanding and artefacts
5. Oscillation between concrete and abstract
6. Four types of design activity
7. Four types of design ripples

These principles are illustrated and described in the following.

5.1. Emergence and unpredictability

In designing mobile interactions the emergence of new artefacts and understanding happens by continually stepping between the four activities of studying, analysing, designing and building. The sequence of activities is not predefined cyclical but flexible and multidirectional, meaning that the designer can jump freely and frequently between activities as needed in response to the continual consideration of outcomes and emergent needs, challenges and opportunities. This allows the process of form-context convergence to be stepwise but unpredictable (Alexander 2002-05) and less orderly (Moggridge 2007), yet continual and cumulative. This is depicted in figure 21 where the upward spiral illustrates the cumulative emergence of artefacts and understanding as the design process unfolds.

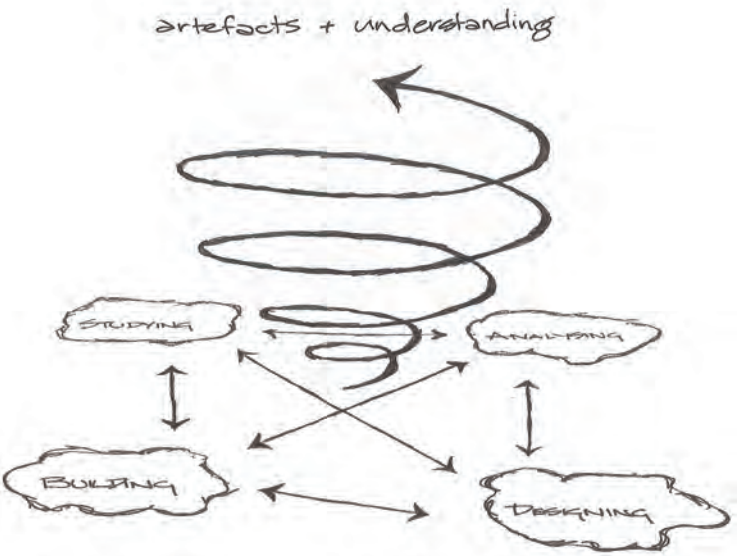

Figure 21. An unpredictable process towards cumulative emergence of artefacts and understanding

Departing further from the circular UCD models, this approach emphasises the evolving character of iterative research and design where each step through a particular activity is purposely different from the last time in terms of focus, scope and type of outcome. For example, the empirical activity of "studying" is different depending on whether it is an early activity of inquiring into the context of a design challenge, or if it is a later activity of inquiring into the user experience of a new interactive prototype system. Similarly, theoretical research involves different levels of analytical abstraction depending on how many steps we have been through, and leads to increasingly higher levels of understanding from each oscillation between the concrete and the abstract. As the process unfolds over time, designs are increasingly detailed and refined, and the artefacts we produce are created with increasing levels of fidelity and completeness.

This view on the interaction design process obviously takes some of its inspiration from Boehm's (1988) spiral model for systems development iterating through particular phases, emphasising that each iteration is different from, and builds on, the previous one. But it is different from Boehm's model in the sense that it does not to the same degree dictate a spiralling sequence of specific activities in detail, and that it traces the processes through very different types of stages. Also, whereas Boehm's model is a tool for managing a software development process through careful planning and risk management, the continually cumulative aspect of designing mobile interactions serves the purpose of illustrating that each step of studying, analysing, designing and building creates additional empirical, theoretical, creative, and technical insight and value in relation to the design that unfolds from the process.

5.2. Form and context unity

The basic unit of analysis in my view on the design of mobile interactions is the unity of form and context. Putting the unity of form and context in the centre echoes the contextual view that the world is inherently dynamic, that the relationship between context and form is a continually changing one, and that design is therefore about the construction of both of these in concert. This view essentially transcends user- and technology-centeredness. The synthesis of form and context is illustrated in figure 22 where these are depicted as an intertwined unity, creating a whole that is bigger than the sum of its individual parts.

Figure 22. Form and context as an intertwined unity

In the design of mobile interactions the unity of form and context provides a common reference point for the activities of studying, analysing, designing and building. Echoing the early work of Alexander (1964), "form" does not just mean shape, but is the unity of *shape, look, function* and *content* – i.e. the interactive system artefacts we design. Context is what defines or frames the situation in which these interactive systems or forms are deployed. Elaborating on Alexander's work, the design of mobile interactions is about actively designing not only the form but also the context – i.e. designing new use situations and practices.

5.3. Form and context convergence

The unpredictable and continual process of emergence and the unity of form and context are tied together in figure 23, providing an overall picture of my view on the design of mobile interactions. In this view on interaction design the unity of form and context is continually explored and refined by stepping between the four activities of *studying, analysing, designing and building* in an unpredictable order gradually leading to the emergence of new artefacts and understanding. Throughout this process, the designer can step from any of the four corners to any of the others, meaning that the sequence of activities is not fixed but flexible. The result of the process is the gradual and unpredictable emergence of form-context convergence.

Each of the four activities contribute to the unfolding of design and gradual convergence of form and context through "ripples" of *assessment, abstraction, exploration and synthesis* towards the specific ensemble of form and context in the centre. In stepping freely between activities, the interaction design process oscillates between producing *understanding* and *artefacts*, and between working with the *concrete* and with the *abstract.*

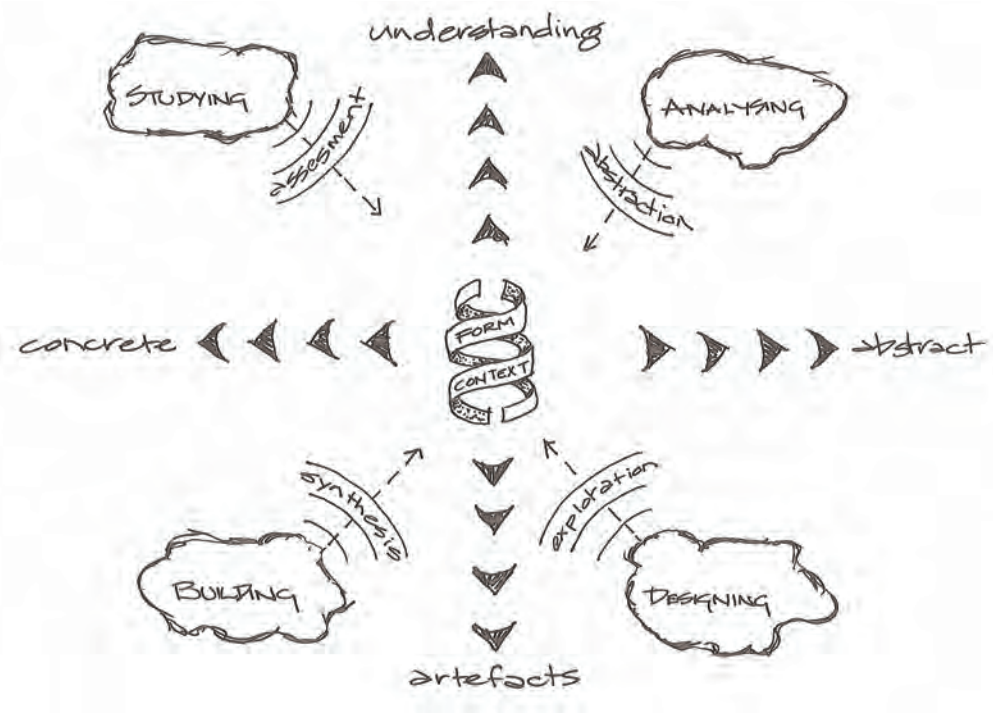

Figure 23. Form and context convergence

The proposed model above encourages a more flexible and pragmatic way of designing mobile interactions, while at the same time defining a shared focus for all activities and describing how they each contribute to the unfolding of the whole.

5.4. Between understanding and artefacts

The distinction between producing understanding and artefacts reflects the contextual view that design is a matter of constructing both problem-understandings and solution-propositions through a cyclical process of learning about a situation, and responding to it through suggestions for design. This is illustrated in figure 24 depicting a design process with oscillations of changing frequencies and amplitude, reflecting the continual and unpredictable sequence of activities, and a tendency towards increasingly mature understanding and artefacts.

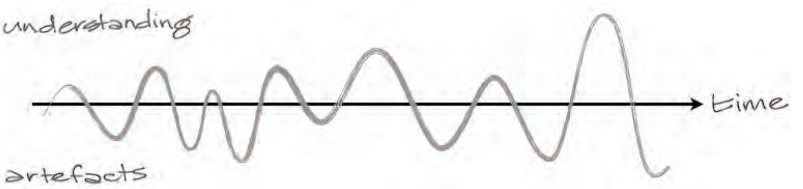

Figure 24. Oscillating between producing understanding and artefacts

In designing mobile interactions, understanding results from the activities of studying and analysing, and artefacts results from designing and building. Understanding is the foundation on which artefacts are designed and built, and artefacts are vehicles for creating understanding through study and analysis. Artefacts cover the range of tangible design products emerging from the process such as sketches, models, mock-ups, simulations, prototypes, and functional systems. On the opposite side, understanding covers the range of less tangible products from the process such as empirical data, personas, scenarios, models, concepts, frameworks, and theory.

5.5. Between concrete and abstract

Introducing a distinction into the form-context convergence model in figure 23 between working with the concrete and working with the abstract is inspired by related discussions of the process of interleaved research and design by, for example, Dubberly et al. (2008), IDEO (2009), Mendel & Yeager (2010) and Dubberly & Evenson (2011). In these discussions it is suggested that the two major phases of a design process of analysis and synthesis (respectively leading to understanding and to artefacts) both involve an orthogonal continuum between "the concrete work we inhabit or could inhabit" and "abstractions and models of what is or what could be, which we imagine and share with others" (Dubberly et al. 2008). It is by elevating our understanding from a concrete to an abstract level before attempting to move from understanding towards new form (i.e. interactive systems), and by exploring new form opportunities in the abstract before implementing and assessing interactive system artefacts in the concrete, that we are able to talk about a process as one of *design* as opposed to one of simple, or *unselfconscious* (Alexander 1964), form making. Bridging between understanding and artefacts on an abstract rather than a concrete level is also what facilitates the conception of solutions beyond incremental improvements to misfit through unreflective reaction. During the design process we continually shift between these two ends of the orthogonal continuum. This is depicted in figure 25, illustrating the same pattern of oscillations with changing frequencies and amplitude caused by the unpredictable sequence of activities.

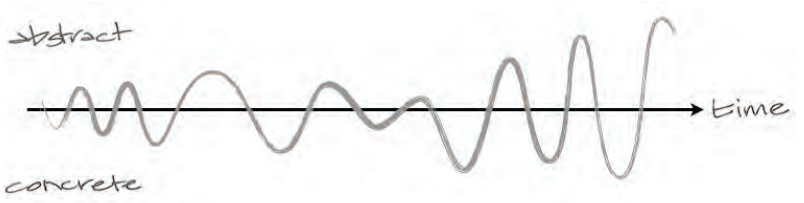

Figure 25. Oscillating between working with the abstract and the concrete

In designing mobile interactions, empirical and technical research takes place in the concrete end of the continuum, dealing with studying and building "what is" and "what could be". In the other end of the continuum, theoretical and creative research takes place in the abstract, analysing and designing what is and what could be. Introducing the concrete-abstract continuum into the model emphasises important differences between studying/analysing and designing/building, and the outcome from these activities in form of ripples of *abstraction* and *synthesis*, as discussed more in section 5.7.

5.6. Four types of design activity

The two orthogonal distinctions between creating understanding or artefacts and between working with the concrete or the abstract define a space involving four distinct types of work: empirical, theoretical, creative, and technical, and illustrate that the design of mobile interactions involves all of these. This is outlined in table 3.

Table 3. Four types of design activity

	Concrete	**Abstract**
Understanding	**Empirical** Studying: working with practice	**Theoretical** Analysing: working with concepts
Artefacts	**Technical** Building: working with prototypes	**Creative** Designing: working with opportunities

In the top left quadrant, mobile interaction design is *empirical*. Empirical work embraces the fundamental concept of modern science that insight must be based on observable evidence – or empirical data. When designing mobile interactions, being in the empirical quadrant means that we are working with the practice or actuality in which our products and solutions are supposed to fit and be used. This work is done through studies of real-world practice using empirical methods such as observations, probes and experimentation, and covers the empirical study of people, technology and context.

In the top right quadrant, mobile interaction design is *theoretical*. Theoretical work seeks to explain empirical phenomena in a consistent way, enabling us to understand and predict a given subject matter. When designing mobile interactions, being in the theoretical quadrant means that we are working with theoretical models and descriptions of our subject matter. This is done through analysing empirical data using theoretical frameworks and concepts derived either from previous research or produced through grounded theory or analysis.

Moving to the bottom right quadrant, mobile interaction design becomes *creative*. Creative work is a process by which a person creates something novel that is of value for other people, society, etc. When designing mobile interactions, being in the creative quadrant means that we are working with new opportunities for mobile computing inspired and informed by our empirical and theoretical insight and our knowledge about the potentials of technology. This is done by conceiving and refining original design ideas and solutions through an iterative process of designing potential artefacts and products making use of flexible and incomplete design instantiations such as sketches, models, and mock-ups, that are purposely suggestive, explorative, and even provocative, rather than descriptive, delimited, and definitive.

Finally, in the bottom left quadrant, mobile interaction design is *technical*. Technical work in this relation seeks to provide concrete instantiations of design propositions or solutions in response to opportunities, problems, challenges or needs. When designing

mobile interactions, being in the technical quadrant means that we are working with prototypes of our proposed design ideas. This is done through the building of artefacts such as simulations, prototypes, or functional systems, investigating technical feasibility, and subsequently enabling empirical investigations of use quality.

5.7. Four types of design ripples

The distinction between four types of interaction design work naturally leads on to four types of design *ripples* emerging from these. These ripples, or pulses, describe what happens in the oscillations between the concrete and the abstract, and between artefacts and understanding. In designing mobile interactions they can be described as pulses of *abstraction, exploration, synthesis, and assessment,* happening respectively when analysing, designing, building and studying (figure 26).

Figure 26. Ripples in the design of mobile interactions

Abstraction happens when progressing towards abstract theoretical frameworks and concepts from, for example, concrete empirical data. It is about learning more from the world around us. In designing mobile interactions the purpose of this transition is to elevate the level of understanding about context beyond concrete observations and descriptive accounts, and distil insights that explain the observed phenomena. This is done by analysing our data, filtering it, prioritizing it, and organizing it, and in doing so moving further and further away from the concrete, and from artefacts.

Exploration happens when moving either from analysis or building to design. While going back to the drawing board informed by experiences with a prototype system is not particularly difficult, bridging the gap between understanding and artefacts is often perceived as the hard bit of the design process. This is because rather than elaborating on a previous stage with the same type of aim, it is an orthogonal direction of work with a completely different type of outcome. As described by Dubberly et al. (2008) this transition is what lies "at the heart of designing" – moving from analysis to design, from problem to solution, from the current situation to the future, from research towards prototypes. It is about opening up a design space for future form. In designing mobile

interactions the purpose of this transition is to use our understanding of context as foundation for investigating and suggesting what the future might look like, or to change our design in light of new technical insight. This is done by speculating, hypothesising, and imagining possible futures in abstract form, and grounded in data and theory.

Synthesis happens when progressing towards concrete prototypes from, for example, abstract design. It is the opposite transition to abstraction and is about making things real. In designing mobile interactions the purpose of this transition is to manifest our design ideas in concrete artefacts showcasing what the future could actually look like and making it available for us in a tangible form that can be put into context. This is done by synthesizing design ideas and technologies into concrete interactive systems, and bringing them to life through prototype implementations investigating the feasibility of our ideas and concepts. In doing so we move further and further away from the abstract.

Assessment happens when moving either from building or analysing to studying. This is the opposite transition to exploration and is about measuring the quality of our design instantiations or examining our theoretical understanding in order to improve them. Like exploration, assessment may involve an orthogonal direction of work from abstraction and synthesis, and crossing a gap that is hard to bridge. Crossing back from artefacts to understanding is difficult and sometimes overlooked as an important and integrated part of the design process. Instead "evaluation" is often left as an appendix, and the subsequent process sadly shortcut by heading unreflected into re-implementation rather than seeking better understanding in order to subsequently explore radically different design opportunities. In designing mobile interactions the purpose of this transition is to return to the empirical realm of work that laid the grounds for our understanding and artefacts in the first place. This is done by feeding our theories or designs back into their context of origin, or intended context of use, assessing their fitness, and using our newly gained insight as the starting point for further abstraction, exploration or synthesis.

5.8. The contextual approach and my own research

The contextual approach described above can be used as a roadmap for summarizing my own research contributions to the design of mobile interactions, as outlined in section 3.2. In my research I have addressed what happens in the four activities of *studying, analysing, designing* and *building* when taking a contextual view, and what the ripples of abstraction, exploration, synthesis and assessment emerging from these activities may involve and look like, and how they may influence the convergence of form and context in specific interaction design projects. Furthermore, my research has addressed the creation of concrete *artefacts* that are contextually grounded, and the creation of abstract *understanding* about the relationships between interactive mobile systems, users, and context. In concert this research illustrates the elements, principles, and dynamics of the contextual approach, and exemplify the types of outcomes that it aspires to produce.

In the next section I will take a closer look at these individual research contributions, and use them to unfold the different activities and outcomes of the contextual approach. I will describe how the five parts of the thesis underpin the contextual approach to mobile interaction design as a whole, and how each chapter contribute to the individual parts.

6. CONTRIBUTIONS

In this section I will summarize and relate my individual research contributions on the design of mobile interactions. These contributions are built on a foundation of research conducted by myself, and in collaboration with colleagues, at Aalborg University in Denmark and The University of Melbourne in Australia between 2001 and 2012. It has included several mobile computing projects concerned with various user groups and use domains – from officers on large container vessels and nurses at hospitals, to young urban residents out on the town and intimate family members at home. Common for these projects are that they have been contextual in nature, taken a designerly approach, and sought to combine and integrate methods and knowledge from different disciplines. Hence, most of the projects have involved empirical, theoretical, creative and technical research, and shifting between the different activities of designing mobile interactions described in the previous section.

The individual contributions are twenty-two journal and conference articles published between 2003 and 2012 included in this thesis as chapters 2-23 (table 4). The first article describes state-of-the-art in mobile interaction design research in the early 2000s, and constitute the foundation for discussion of this back in section 3. The other twenty-one articles are compiled into five parts, each illustrating a specific aspect of designing mobile interactions that I have worked with. Parts I, II, III address the empirical, theoretical, creative and technical activities of studying/evaluating, analysing, designing and building. Parts IV and V address the two different types of outcomes from interaction design: artefacts and understanding.

Table 4. Research themes, questions and selected contributions

Theme	Research question	Contributions
Challenges and opportunities	What are the challenges and opportunities for mobile interaction design research in terms of approaches and focus?	Chapter 2
Part I Studying and analysing	How can we study, analyse and understand aspects of context relevant for mobile interaction design?	Chapters 3, 4, 5, 6
Part II Designing and building	How can we design and build interactive mobile systems grounded in context?	Chapters 7, 8, 9, 10
Part II Improving evaluation	How can we improve our techniques for studying the user experience of mobile interaction design in context?	Chapters 11, 12, 13, 14
Part IV Artefacts	How can we make use of context in the implementation of concrete interactive mobile systems?	Chapters 15, 16, 17, 18, 19
Part V Understanding	How can we abstractly describe and understand the relationships between interactive mobile systems, users, and context?	Chapters 20, 21, 22, 23

Figure 27 below maps the individual chapter contributions in Parts I-V onto the conceptual space introduced previously to describe the different types of design work and their outcomes.

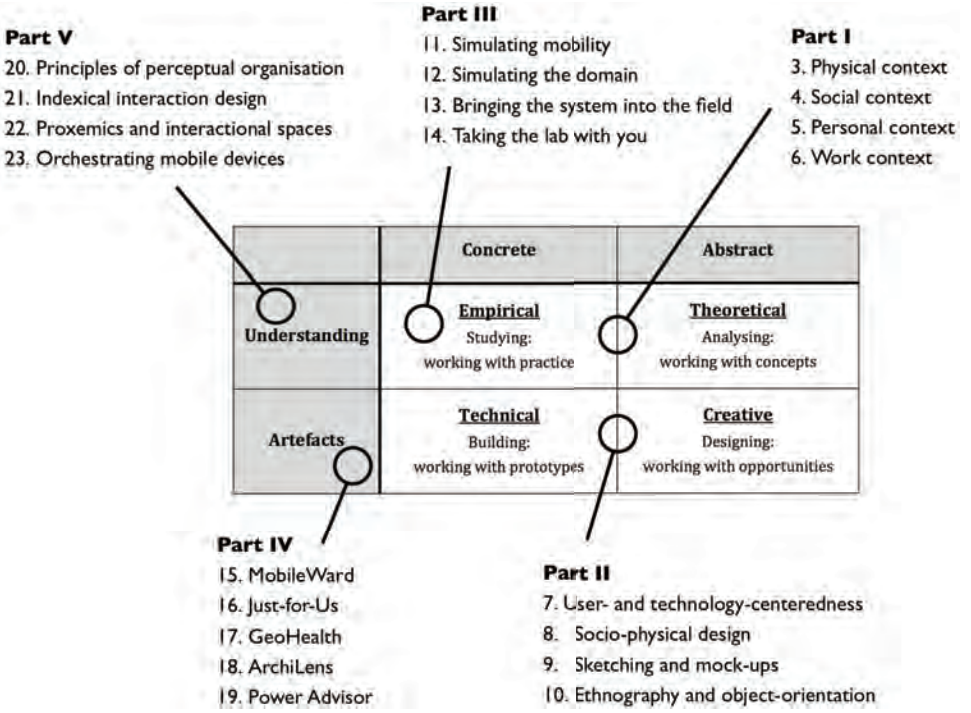

Figure 27. Overview of chapters 3 to 23 in relation to activities in the design of mobile interactions

In the following I will outline the focus of each these five parts, and summarise each of the contributing chapters.

6.1. Part I – Studying and analysing

Part I addresses the question *how can we study, analyse and understand aspects of context relevant for mobile interaction design?* In order to do contextual interaction design we need to understand what context is, for a particular design task. What dimensions of context are important, what role they play, how they interact and influence each other, etc. This is an empirical and theoretical activity where we study form and context in the real world, and elevate our insight from this from a concrete to an abstract level.

Four of my own contributions to this are included in chapters 3-6 and summarized in the following sections. These four chapters each address and explore a particular dimension of context for mobile interaction design: physical, social, personal and work, by specifically investigating four contextual entities: places and surroundings, people and interactions, families and relationships, and tasks and coordination as illustrated in figure 28. The contributions of these works are both methodological and conceptual. Firstly, they offer empirical approaches for studying concrete physical, social, personal and work contexts, and theoretical approaches for analysing them. Secondly, they offer conceptual abstractions of physical, social, personal and work contexts in the form of graphical representations, conceptual frameworks, and structure models derived through analysis of empirical data.

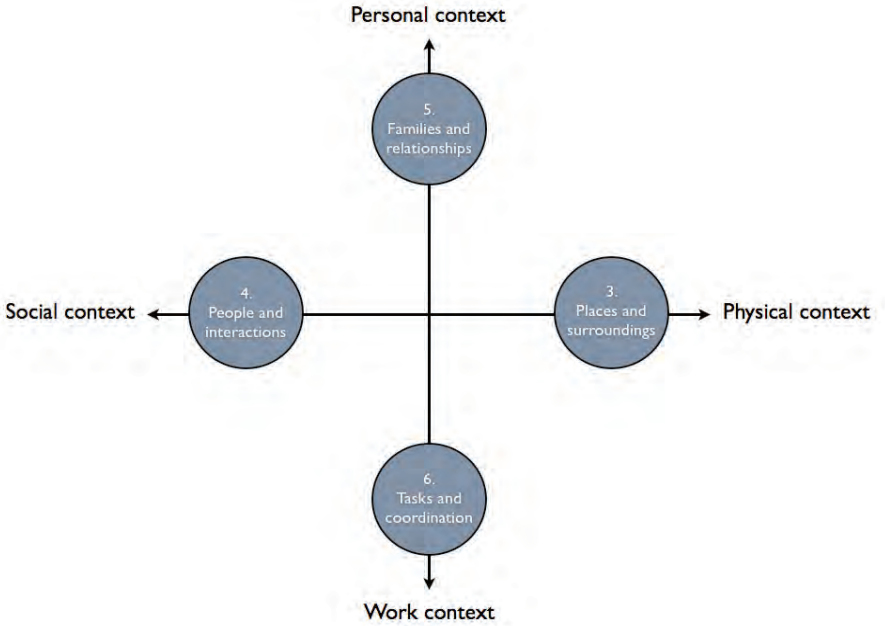

Figure 28. Four dimensions of context investigated in chapters 3-6

In concert the four chapters in Part I illustrate how we can study, analyse and understand different aspects of context relevant for designing mobile interactions. Although context for mobile interaction design is a complex and multi-dimensional concept, it can be broken down into more specific entities or dimensions that can then be studied carefully in detail. Methodologically, there are several potential approaches for studying context empirically. Common for the approaches presented in Part I is that they all involve natural setting research going out into the field and investigating the context of interest first hand. However, as also illustrated in these chapters, this overall approach still leaves room for variety in specific methods and techniques.

Physical context

Chapter 3 investigates physical context. The chapter presents a field study and architectural analysis of a concrete urban environment, Federation Square in Melbourne, Australia. The study was conducted by combining empirical and analytical methods from architecture and city planning developed by Kevin Lynch (1960) and Christopher Alexander et al. (1977) to survey, model and represent prominent architectural and informational aspects of a built environment such as districts, buildings, structures and signage. The result of the study is a descriptive framework summarizing the architectural and informational properties of a built environment. The use of such understanding in mobile interaction design is illustrated through a location-based mobile guide.

Social context

Chapter 4 investigates social context. The chapter presents a field study and sociological analysis of small groups of friends socializing "out on the town" in the same urban area as investigated in chapter 3. The study combined rapid ethnography (Millen 2000), contextual interviews, and grounded analysis (Strauss and Corbin 1990), and was

guided conceptually by McCullough's (2004) typology for situated interactions. This resulted in a conceptual framework encapsulating and describing the interplay between people, activity and places during situated social interactions in an urban environment structured around the three key concepts of knowledge, situation and motivation. The use of such understanding in the design of mobile interactions is illustrated through a context-aware mobile guide representing and adapting to social context.

Personal context
Chapter 5 investigates personal context. The chapter distils eight dimensions of intimacy from the literature, and presents a longitudinal field study of technology-mediated intimacy and strong-tie relationships with six families in Melbourne, Australia. In order to minimize researcher intervention in peoples' private lives, the study deployed the "auto-ethnographic" approach of cultural probes (Gaver et al. 1999) in combination with contextual interviews. The outcome of the study is a thematic understanding of what constitutes intimacy and how interactive systems are appropriated and used within intimate relationships. The use of such insight in mobile interaction design is illustrated through three early design ideas for technologies supporting intimacy.

Work context
Chapter 6 investigates work context. The chapter presents an ethnographic field study of communication on board large container vessels while manoeuvring inside harbour basins (Andersen 2001), and a simulator study of prototype technology in use. The outcome of the study is a detailed understanding of communication and coordination in the work context, based on Winograd and Flores' (1986) model of conversation for action. From this understanding it is possible to model communication flow in distributed work and use this to facilitate persistency in communication. This is demonstrated through the design of a mobile text-based communication system.

6.2. Part II – Designing and building

Part II addresses the question *how can we design and build interactive mobile systems grounded in context?* In order to make use of our empirical and theoretical understanding of context in the exploration of a design space, we need to develop ways of transferring this knowledge into the design activity, develop ways of grounding design ideation and exploration in such input, and support synthesising multitudes of ideas into concrete interactive systems. This activity is creative where we explore opportunities for form-context convergence, and technical where we concretise our ideas into prototypes.

In order to be successful at these it is my belief that interaction designers both need a high degree of free and unrestricted exploration of new design opportunities *as well as* some level of systematisation in order to control and direct the design process within a desired area of focus. Using the terms of Shneiderman (2000) these two requirements reflect two different types of thinking and working within design namely *inspirationalistic creativity* and *structuralistic creativity*. Inspirationalistic creativity is largely intuition-based in concert with preparation and incubation leading to moments of illumination. It promotes techniques such as brainstorming, free association, lateral thinking and divergence to support idea generation (Luther and Diakopoulos 2007). Although the outcome of inspirationalistic creativity is not necessarily art, much art is

driven by inspirationalistic creativity. In contrast, structuralistic creativity is driven by more systematic approaches and highlights the importance of methodical exploration of possible solutions by systematically breaking down the challenge and structuring the response accordingly. It promotes techniques such as flow charts, decision trees, and other structured diagrams (Shneiderman 2000), and would also include software engineering modelling such as object-oriented analysis. Although the outcome of structuralistic creativity is not necessarily science, much science is driven by structuralistic creativity. As inspirationalistic and structuralistic creativity are often in conflict with each other, aspiring to support and maintain both modes of thinking and working when designing mobile interactions we are faced with a challenge of devising methods and techniques that are interdisciplinary and on the intersection of arts and science.

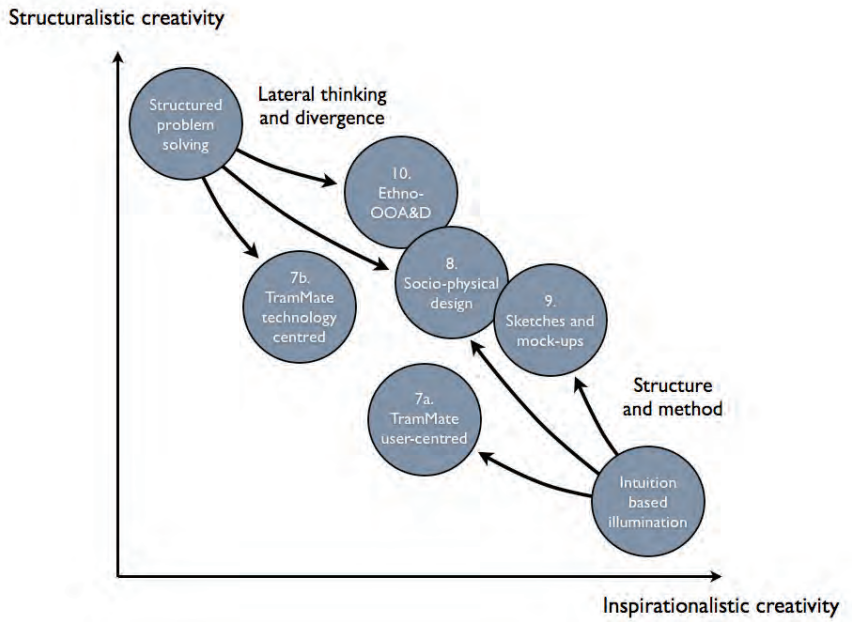

Figure 29. Achieving structuralistic and inspirationalistic creativity in mobile interaction design

Four of my own contributions on this topic are included in chapters 7-10. Figure 29 maps these four chapters into a space between inspirationalistic and structuralistic creativity, illustrating how they each represent a shift from pure structured problem solving or intuition based illumination towards a hybrid approach to designing mobile interactions involving both types of creativity. Chapters 7-10 address and discuss possible ways of supporting the creative process of moving from abstract understanding towards concrete artefacts by using *form and context ensembles* as the central point of gravity for design exploration. The contributions of these works are primarily methodological illustrated through case studies of mobile interaction design. Together they offer a palette of techniques for exploring a design space in an empirically and theoretically informed way. This is done through the use of various representations of context and form, such as abstract models, sketches, paper prototypes, and mock-ups in varying levels of fidelity, in combination with stepwise descriptions for the use of these representations in the

continual development and refinement of design from initial activities of broad ideation and exploration, to the later activities of detailed explanation and specification.

Together the four chapters in Part II illustrate how we can support contextual design of mobile interactions by combining inspirationalistic creativity and structuralistic creativity. Although this is a challenging task with opposing interests and ways of thinking and working, there are several ways where a creative and contextual process of designing mobile interactions can include a high degree of free and unrestricted exploration of new design opportunities as well as some level of systematization.

User- and technology-centeredness

Chapter 7 discusses user- and technology-centeredness. In this chapter we ground the design of mobile interactions in our experiences with processes that are either user- or technology-centred. The chapter provides a meta-commentary on the relative values and limitations of inspirationalistic and structuralistic creativity for addressing the same mobile interaction design brief as a part of the "TramMate" project in Melbourne, Australia (Kjeldskov et al. 2003). The chapter concludes that neither of the two approaches was superior, but that in concert they appeared to have potentials for complementing each other very well within a broader approach: the user-centred approach grounding design in the contextual complexity of current practice, and the technology-centred approach providing a counterpoint grounded in the context of future technical possibilities.

Socio-physical design

Chapter 8 explores a socio-physical approach to design. In this chapter we propose and illustrate an inter-disciplinary approach to designing mobile interactions combining rapid ethnography, architectural analysis, design sketching and paper prototyping. The socio-physical approach combines inspirationalistic and structuralistic creativity by, on one hand, informing unrestricted idea generation through inspirational and ambiguous representations of context and, on the other hand, offering a stepwise and structured process for translating the understanding of socio-physical context into specific design ideas. The approach was explored through a mobile interaction design case study following on from the empirical work presented in chapters 3 and 4 and leading to the design and implementation of an interactive mobile prototype system.

Sketches and mock-ups

Chapter 9 illustrates the use of sketches and mock-ups. In this chapter we revisit the study of intimacy from chapter 5, and describe how our understanding of personal context was used to inform mobile interaction design. The chapter discusses the use of interactive technologies to support intimacy and describes our activities of ideation and interaction design. These took place through a semi-structured process of sketching and mock-up development in collaboration with study participants, adding a level of structure and method to the design team's mainly inspirationalistic type of creativity. The diversity in scope and form of designs produced illustrate how sketches and mock-ups are a highly flexible means for exploring and communicating ideas in a heterogenous design team.

Ethnography and object-orientation
Chapter 10 explores the combination of ethnography and object-orientation. In this chapter we propose and describe an inter-disciplinary combination of methods for supporting the design and development of interactive mobile computer systems. This combines inspirationalistic and structuralistic creativity by integrating an open-ended method with a structured one. The chapter presents two case studies of mobile system development, following on from the work presented in chapter 6. The two studies show that ethnographic data is highly valuable for developing object-oriented models by providing contextual richness. In return, object-oriented analysis is a valuable way of working with ethnographic field data by providing structure. Combining the two we were able to strongly inform system design with our ethnographic field studies.

6.3. Part III – Improving evaluation

Part III addresses the question *how can we improve our techniques for studying the user experience of mobile interaction design in context?* In order to realistically assess the quality of mobile interaction designs we need to systematically study prototypes under conditions that are appropriately representative of the future use context. This is an empirical activity where we study concrete artefacts in actual use, with the purpose of understanding the interplay between form and context.

The challenge of assessing *mobile* interaction design as opposed to non-mobile has led to a long lasting, and sometimes heated, discussion of what methods and techniques are appropriate. Most notably, this discussion has been contrasting field-based approaches with lab-based ones, polarising the research field into two distinct camps of thought, one taking an ethnographic research approach, the other taking a usability engineering one. Ethnographic field studies are characterized by taking place in "the real world" with researchers spending considerable amounts of time in the actual context of their study. Data is typically gathered through observations and interviews, and the studied phenomena (i.e. interactive mobile systems in use) are placed in a social and cultural context. The major advantages of ethnographies are the gathering of large amount of rich and grounded data, and a high level of *ecological validity* (methods, materials and settings resembling the real-life situation being investigated). The major disadvantages are unknown biases, unknown external validity/generalizability and, typically, lack of control. In contrast, usability evaluations traditionally take place in controlled environments created for the purpose of research, and data is gathered through video recording, logging, questionnaires, and interviews. The major advantages of lab based usability evaluations are the ability to focus in detail on specific phenomena of interest, and large experimental *control* before and during the study. Usability evaluations are also highly replicable and allow high quality data collection. The major disadvantages are the limited relations to the real world, unknown external validity and, typically, low level of ecological validity.

For my part, I find myself in-between these two camps of thought – my position being that natural setting research is an essential approach in most designs of mobile interactions, with its advantage of high ecological validity. At the same time, however, I also believe that some aspects of mobile interaction design can advantageously be

assessed through artificial setting research, with the benefit of high levels of control. Hence, in order to shed light on the topic, in 2003 we carried out a comparative study of the added value of evaluating the usability of context-aware interactive mobile system in the field (Kjeldskov et al. 2004a). To our surprise, we found that *if looking for usability problems* the added value of going in to the field was relatively small, while the added complexity and time spent was considerably high. This finding led us to ask the question if field studies were really "worth the hassle", leading to widespread debate in the research field and numerous follow-up studies and articles[4]. In hindsight, judging from the subsequent, sometimes rather simplistic and black-or-white, debate we probably asked the wrong question. Rather than "if" it is worth the hassle the question is really "when" and "how" it can be advantageous to study mobile interaction design in the field, and what we should be looking for out there, beyond usability problems.

This question remains largely unanswered in a balanced and unbiased way that does not simply restate existing disciplinary doctrines. Even better, however, the question we really ought to be asking ourselves is how the challenges and advantages of field and lab-based evaluation studies can be overcome and combined through new hybrid methods and techniques integrating elements of the two? As research control and the ecological validity of a study are often, fundamentally, in conflict with each other, aspiring to support them both presents us with a challenge to develop methods and techniques that are essentially interdisciplinary on the intersection between social and technical science.

Four of my own contributions on this topic are included in chapters 11-14.

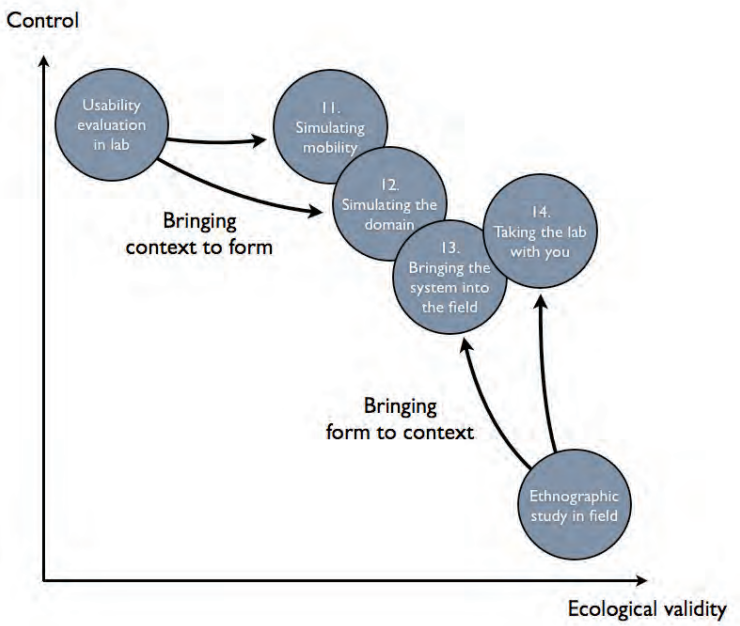

Figure 30. Achieving control and ecological validity when evaluating interactive mobile systems

4) See, for example, the articles "Its worth the Hassle" by Nielsen et al. (2006) and "Why its worth the hassle" by Rogers et al. (2007).

Figure 30 maps these four chapters into a space between control and ecological validity, illustrating how they each represent a shift from pure ethnographic studies in the field or pure usability evaluations in the lab towards a hybrid approach aspiring for both methodological qualities. This is done by combining elements from usability evaluation methods with elements of ethnographic field study methods – simulating context when evaluating in controlled environments, and guiding focus and improving data collection when evaluating in the real world. Collectively, the four chapters in section III illustrate different ways of evaluating mobile interaction design with both ecological validity and control. The described evaluation methods show how elements of context can be simulated in controlled artificial setting research environments, and how means for guiding focus and enabling high quality data collection can be applied to natural setting research environments. The methods also illustrate how new hybrid approaches can be developed by integrating elements from different disciplinary traditions.

Simulating mobility

Chapter 11 investigates how mobility can be simulated in a controlled setting. In this chapter we aim to increase the ecological validity of laboratory evaluations by simulating the user being physically mobile during use. The chapter presents and evaluates five lab techniques involving various aspects of physical motion combined with either needs for navigation in physical space or division of attention, using the case of walking down a pedestrian street as base line reference. The findings from the study show that each of the proposed techniques had similarities to the real world reference, but that none of them were completely identical to the field condition. The best simulation of mobility in the real world context was obtained when using a treadmill running at varying speed.

Simulating the domain

Chapter 12 investigates how use domains can be simulated in controlled settings. In this chapter we aim to increase the ecological validity of laboratory evaluations by simulating the use domains of interactive mobile systems. The chapter presents two case studies of mobile interaction design evaluations in controlled high-fidelity simulations of the real world. Findings show that simulating the domain provided better results than the traditional non-contextual lab approach, but that the field evaluation provided additional insight into real world use. The study concludes that although not as ecologically valid as a field study, it is possible to obtain a higher level of ecological validity by simulating significant elements of a use domain in controlled laboratory settings.

Bringing the system into the field

Chapter 13 investigates how a structured evaluation can be carried out in the field. In this chapter we aim to facilitate increased control in field evaluations without compromising its ecological validity. The chapter presents a multi-method evaluation of an interactive mobile system with the purpose of investigating how a field-based evaluation guided by tasks performs against other evaluation methods. Findings show that each of the methods had its own benefits. In relation to context, however, the field evaluation was able to uniquely highlight a number of issues of real world use. The study concludes that a field study, with a high level of ecological validity, can advantageously be combined with techniques from lab-based evaluations if more control and replicability is needed.

Taking the lab with you
Chapter 14 investigates how data collection can be improved in the field. In this chapter we aim at facilitating increased control and better data collection in field studies by exploring the use of small wireless cameras attached to users and their mobile devices. The chapter presents the development and use of a "field-laboratory" over four years of evaluating mobile interaction design in the field. It describes the current setup and explains the rationales for key decisions on technology and form factors. The study shows that it is possible to collect ecologically valid field data about mobile interaction design in use in a quality matching stationary usability laboratories by means of a field-lab. It also shows that field-labs can be made small, lightweight, and operational for hours.

6.4. Part IV – Artefacts

Part IV addresses the question *how can we make use of context in the implementation of concrete interactive mobile systems?* In order to create actual interaction design artefacts, we need to know what is technologically possible now and in the near future, and we need to know how emerging technologies can be used for pushing this frontier further. This requires building concrete interactive mobile systems exploring the feasibility of abstract design ideas in practice.

The technical dimension of designing mobile interactions contains several specific topic areas with their own challenges and focus, such as input and output devices, advanced graphic interfaces, mobile web browsing, wireless network connectivity, and context-awareness. From a mobile interaction design perspective these are all important technical topic areas, which if advanced further could potentially facilitate the creation of new and better design solutions. The technical focus of my own research in designing mobile interactions falls within the area of "context-awareness". Within this area there has been a lot of technical research into possible ways of making mobile systems capable of sensing and automatically adapting to their context, and using this capability for streamlining user interaction. Context-aware mobile systems can be differentiated technically in several ways. Chen and Kotz (2000) distinguish between *active* and *passive* context-awareness describing whether the system 1) actively takes initiative to push context-based content to the user, or 2) passively awaits the user to perform an act of information pull. Another distinction can be derived from Oulasvirta et al. (2005) who argue that the debate about context consists of two disparate camps of thought: Realism or Constructivism. As discussed in (Kjeldskov et al. 2012b), the philosophical difference between these two results in two distinct types of context-aware systems that either 1) automatically adapt their behaviour to the context as perceived by the computer system, or 2) mediate context information for the user to interpret and make use of. We label these two classes *adaptive* and *mediated* context-awareness.

Five of my own contributions to the building of concrete interactive mobile systems are included in chapters 15-19. These contributions present our experiences with the technical implementation of five prototype systems, which have all been studied in use in the field. Figure 31 map these five systems into a two-dimensional space defined by the four different characteristics of context-aware systems described above: active vs. passive and adaptive vs. mediated.

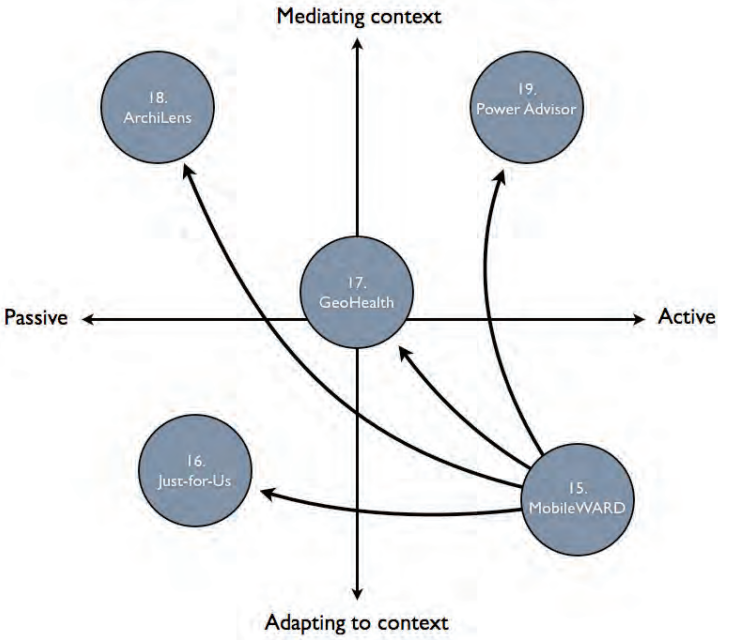

Figure 31. Five interactive prototypes mapped out in terms of their contextual characteristics

The sequential order of the systems represents the order in which they were built. This sequence also illustrates a development in thinking about contextual systems from traditional adaptive and active context-awareness in MobileWARD, towards other types of interactive mobile systems that are partly or entirely passive, and partly or entirely mediated.

Collectively, the five chapters in section IV illustrate different ways of making explicit use of context in the creation of concrete artefacts through the exploration of emerging technologies as they have become available on commercial mobile devices. The described system implementations illustrate how the feasibility of mobile interaction design ideas can be investigated through the technical construction of functional interactive prototype systems, which can then be used as research vehicles for empirical studies in realistic use contexts. The selection of systems discussed in section IV also illustrates how an interaction design space can be defined technically for a specific class of interactive mobile systems, in this case context-aware systems being active/passive and adaptive/mediated, and how such a technical interaction design space can be used to guide the design focus towards deliberately exploring particular technical properties.

MobileWARD

Chapter 15 presents MobileWARD. In this chapter we explore the construction of an interactive context-aware mobile prototype system for the healthcare domain. The system deploys a combination of active and adaptive context-awareness by automatically pushing information and functionality to the user filtered on the basis of their location, current work activities and people nearby. The chapter presents the details of the prototype system and results from an empirical study of its use. It concludes that context-aware mobile information systems hold potential value within the healthcare

domain as a component of a ubiquitous computing environment supporting the mobile and distributed nature of work activities in this domain. However, the implementation of interaction designs for such systems is highly complex and must be carefully thought out and evaluated in order to ensure a good fit between systems, users, and their context.

Just-for-Us

Chapter 16 presents Just-for-Us. In this chapter we explore the construction of an interactive context-aware mobile prototype system for socialising in the city. The system primarily deploys passive adaptive context-awareness by filtering user requested content and functionality on the basis of their context. Just-for-Us was an early attempt at making mobile context-aware systems web-based. The aim of this technical approach was to explore system alternative architectures that would allow such mobile systems to benefit from the fast paced development of new programming facilities for the mobile web. The chapter concludes that the web-based approach holds interesting potentials for the creation of highly dynamic and graphical mobile context-aware applications, but that mobile web browsers and programming environments of the time lacked a series of capabilities for handling dynamic exchange of information between clients and servers.

GeoHealth

Chapter 17 presents GeoHealth. In this chapter we explore the construction of a web-based location-based service for home healthcare workers distributed over a large geographical area. The system combines active and passive context-awareness depending on importance of information, and combines adaptation and mediation of context through a mesh-up of information from various sources on an interactive map. Extending directly from the work presented in chapter 16, the GeoHealth system explores the powers of Web 2.0 technologies in combination with GPS positioning, Google Maps and the Mobile Internet. The chapter presents the prototype system in detail followed by results from an empirical study of its use. It shows that mobile location-based services built around Web 2.0 technologies and interactive maps have unexploited potentials for mobile interaction design within the domain of home healthcare.

ArchiLens

Chapter 18 presents ArchiLens. In this chapter we explore the construction of a mobile augmented reality system for architectural visualization. The system deploys passive context-awareness and mediates contextual information by allowing the user to explore the visual and spatial characteristics of their future house in context**.** This is done by overlaying the 3D scene onto the live images from the phone's built-in camera. The ArchiLens system was implemented as an application for the Android operating system, making use of its powerful graphics engine mainly designed for interactive 3D games. The chapter presents the prototype in detail followed by results from a study of use with 40 participants. It show that the 3D capabilities of modern mobile devices in combination with their contextual sensors and built-in high quality video cameras have strong potentials as a platform for the design of mobile interactions.

Power Advisor
Chapter 19 presents Power Advisor. In this chapter we explore the construction of an interactive mobile system to promote sustainability by allowing people to monitor their domestic electricity consumption and adjust usage behaviour accordingly. The system deploys active and mediated context-awareness by pushing information about the household's electricity consumption to the user as a resource for interpretation and exploration. This information is collected wirelessly from a "smart" power meter unit. The Power Advisor system was implemented as a mobile web application allowing it to be used on Android and iOS enabled devices. The chapter presents the prototype system in detail followed by results from a study of use in 10 households over a period of 7 weeks. The findings provide insight into peoples awareness of electricity consumption in their home and how this may be influenced through interaction design of mobile systems.

6.5. Part V – Understanding

Part V addresses the question *how can we abstractly describe and understand the relationships between interactive mobile systems, users and context?* In order to facilitate research progress beyond small incremental steps from one design to the next, we need to develop a cumulative body of knowledge that can help explain, theoretically, the relationship between people, technology, and their context. This requires research elevating our understanding from a concrete to an abstract level.

With form-context convergence as the central unit of analysis, the theoretical approach to this phase of research is inherently one of holism rather than of reductionism. Whereas reductionism believes that complex systems can be understood by breaking them down into fundamental parts, which can then be studied in detail individually, holism believes the opposite, that the whole is larger than the sum of the parts and therefore can not be understood through explanation of its components alone but has to be considered in its totality. This can be done by investigating the whole through theoretical and conceptual lenses that focus on explaining the relations and interactions between elements in a system rather than on their individual mechanics.

Four of my own contributions on this topic of understanding the relationships between interactive mobile systems, users, and context, are included in chapters 20-23. When trying to understand the contextual user experience of a mobile interaction design, the central question is how people create meaning from such artefacts in context. Figure 32 illustrates how these four chapters each take an individual approach to the issue of sense making in context on different levels of abstraction – the way we perceive the world by identifying meaningful patterns and wholes, the way we interpret the world by assigning meaning to signs, the way we use our joint embodied presence in the world to create shared meanings, and the way we organise and orchestrate the world around us in order to create meaningful systems of systems.

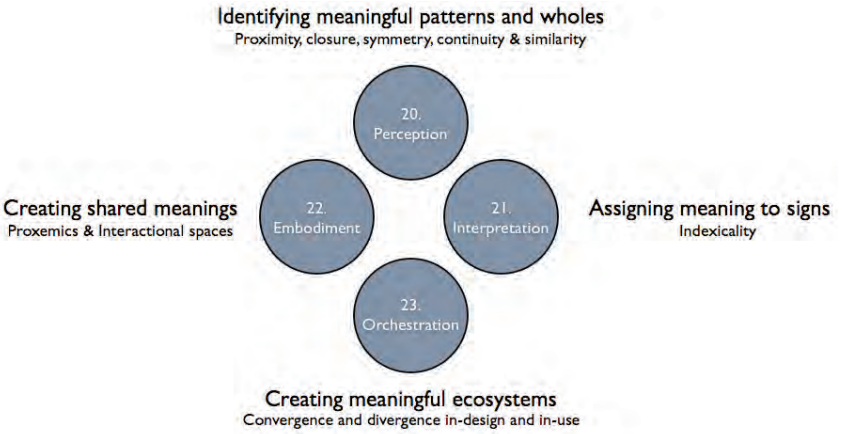

Figure 32. Four approaches to understanding contextual mobile user experience

Principles of perceptual organisation

Chapter 20 presents and discusses five principles that can be applied for explaining how people identify meaningful patterns and wholes from ensembles of mobile systems and their context. The discussion is informed by a field study of mobile user experience at Federation Square in Melbourne, Australia, and takes its theoretical inspiration from the discipline of Gestalt psychology. Based on a theoretical analysis of our empirical findings, we argue that the user experience of location-based mobile interaction designs in context can be described and understood through Gestalt theory's five principles of perceptual organisation: *proximity, closure, symmetry, continuity,* and *similarity*. Specifically, we argue that these principles assist us in explaining how people create meaningful wholes from incomplete and fragmented information on mobile devices. They do so by "drawing from a larger canvas" to which both mobile devices and their context are contributing. Consequently, as mobile interaction designers we need to design for this "larger canvas" rather than merely for the "smaller canvas" of the mobile device in isolation.

Indexical interaction design

Chapter 21 discusses how people interpret information representations on mobile devices in context by assigning meaning to indexical signs. The discussion is informed by three field studies of mobile user experience in Denmark and Australia, and is grounded theoretically in the discipline of semiotics. Based on our empirical and analytical work, we argue that the relationship between users, user interface representations, and context can be described and understood through the semiotic concept of *indexicality.* In relation to mobile interaction design, we argue that information in an interactive mobile system can be understood as a special type of indexical sign, where meaning is created through interpretation of the ensemble of system and context. We also argue that increasing the level of indexicality in an information representation by locating it in time and space results in a reduction of symbolic and iconic representations required to communicate a specific piece of information. Of particular importance for the design of mobile interactions, this allows a reduction of explicit information presented to the user.

Proxemics and interactional spaces

Chapter 22 discusses how people create shared meanings through embodiment in shared physical spaces, and how an understanding of embodiment and proxemics can be used to guide the design of interactional spaces or digital artefact ecologies. The discussion is informed by a theoretical analysis of human interaction in shared physical spaces drawing on the philosophical foundations of Husserl, Heidegger and Merleau-Ponty. The key point is that coordinated action, meaning-making and intersubjective understanding are shaped, in part, from our embodied actions in space and the availability to others of these actions, for example, the way we move, point, touch and gesture in relation to objects and other people. In respect to understanding mobile device user experiences we argue that this is profoundly influenced by spatial factors such as proxemics and the physical design of the interactional spaces in which they are used. We exemplify this through the "blended interaction space" prototype including an ecosystem of interactive surfaces and devices and facilitating various forms of "proxemic interactions" (Greenberg et al. 2011).

Orchestrating mobile devices

Chapter 23 discusses how people create and orchestrate meaningful digital ecosystems of interactive mobile systems and devices. The discussion is informed by a cultural probe study of early adopters of mobile devices in Melbourne, Australia, and takes its offset in the debate about convergence versus divergence as principles for mobile interaction design (as discussed in section 2.1). The chapter presents three seemingly irreconcilable perspectives on the relationship between functionality and user experience drawn from the literature, and argues that these are, in fact, complementary views, when observed in a broader perspective. The key point in this argument is the observation that convergence and divergence are not just principles of design, but also principles of orchestration in use.

7. CONCLUSIONS

In this final section I briefly summarize the main conclusions of my work. The conclusions are expressed as eight lessons about the design of mobile interactions as a matter of continual convergence of form and context, based on my experiences from taking this view and approach in my own research over the last decade.

Table 5. Key lessons about the design of mobile interactions

Lesson 1:	Mobile interaction design has become a discipline at the intersection between technology and liberal arts where the best results yield from combining the two. Doing this well requires approaches that transcend technology- and user-centeredness.
Lesson 2:	Form-context unity is a central concept in all phases of designing mobile interactions. This makes it a suitable higher-level unit of analysis for interdisciplinary research and design transcending focus beyond technology- or user-centeredness.
Lesson 3:	Contextual interaction design guides the continual convergence of form and context through a designerly process of shifting freely between empirical, theoretical, creative and technical work, oscillating between understanding and artefacts, concrete and abstract.
Lesson 4:	In studying and analysing the foundations for designing mobile interactions, a contextual approach defines a broad perspective on the interplay between both users, technology, and advocates the use of theories, concepts and frameworks from different disciplines.
Lesson 5:	In designing and building interactive mobile systems, a contextual approach supports open-minded, yet structured, exploration of design opportunities and prototypes by facilitating both inspirationalistic and structuralistic creativity.
Lesson 6:	In studying the user experience of mobile interaction design, a contextual approach adds improved techniques that facilitate both control and ecological validity to the palette of methods for evaluating interactive mobile systems.
Lesson 7:	In building interactive mobile system artefacts, a contextual approach promotes convergence of form and context that make close relationships between content, functionality, interaction, system behaviour and the surrounding context.
Lesson 8:	In understanding the user experience of mobile interaction design, a contextual approach promotes a holistic perspective on the interplay between people, interactive systems, and context, seeing it as a whole that is larger than the sum of its parts.

Lesson 1: transcending technology- and user-centeredness

Mobile interaction design has become a discipline at the intersection between technology and liberal arts where the best results yield from combining the two. Doing this well requires approaches that transcend technology- and user-centeredness. Although current mobile interaction design is multi-methodological and involves multiple disciplines, there is still an assumption that users and technology can advantageously be studied separately. In contrast, taking a contextual approach to interaction design means that focus is explicitly broadened to the higher-level unity of form and context. Combining and integrating methods and techniques from different disciplines into new and hybrid ones, with a transcendent unit of analysis, allows us to maintain this broader focus throughout all of the different activities of the interaction design process.

Lesson 2: form-context unity

Form-context unity is a central concept in all phases of designing mobile interactions. This makes it a suitable higher-level unit of analysis for interdisciplinary research and design transcending focus beyond technology- or user-centeredness. Viewing the design of mobile interactions as continual convergence of form and context facilitates a paradigmatic shift stimulating new ways of conceptualizing and working by framing new issues, research questions and challenges beyond those of the disciplines involved with mobile interaction design individually. As a central unit of analysis, form-context unity provides a wide enough scope to encompass the more extensive phenomena of mobile interaction design user experience in a holistic way. From a contextual perspective the activities of studying, analysing, designing and building are all about considering the ensemble of a particular form in relation to its context: an interactive mobile system in relation to users, technology, settings, activities, etc. Consequently, the interaction design process becomes neither user- nor technology-centred but instead continuously includes both of these viewpoints within a broader perspective.

Lesson 3: a designerly way

Contextual approaches to interaction design guides the continual convergence of form and context through an unpredictable process of shifting freely between empirical, theoretical, creative and technical work, oscillating between producing understanding and artefacts, and between working in the concrete and in the abstract. The process of stepping freely between the activities of studying, analysing, designing and building creates what can be described as ripples of abstraction, exploration, synthesis, and assessment towards the unity of form and context, which is always in focus and continually evolving. In this way, viewing the design of mobile interactions as continual convergence of form and context promotes a designerly way of thinking and working where new knowledge, artefacts, and contexts emerge from a series of intentionally short and open ended steps. It allows us to do mobile interaction design that is intentionally rhetorical, exploratory, emergent, opportunistic, abductive, reflective, ambiguous, and risky, and it allows us to reach beyond interaction design as a matter of problem setting and solving, and treat it also as a matter of creating entirely new practices – enabling humans to do things in their lives that they couldn't do before.

Lesson 4: studying and analysing

In studying the background and foundations for designing mobile interactions, viewing interaction design as continual convergence of form and context defines a broader perspective than, for example, a user- or technology-oriented approach, and directs the focus of attention towards understanding dimensions of context of particular importance or relevance to the specific case. In analysing empirical data, the design of mobile interactions retains this broader perspective and advocates the use of theories, concepts and frameworks from different disciplines for elevating empirically grounded understanding from concrete to abstract. Physical, social, personal, and work context are examples of such dimensions of context, which I have specifically investigated in my work presented here. Taking a contextual approach during empirical and theoretical activities of interaction design means that both users and technology, as well as other contextual factors, are of importance, but that the central unit of analysis transcends these for a holistic perspective on the form-context ensemble to which they all contribute.

Lesson 5: designing and building

In designing and building interactive mobile systems, the contextual approach supports the process of moving from abstract understanding to concrete artefacts by encouraging and supporting both inspirationalistic and structuralistic creativity in the exploration of design opportunities and prototypes. This is done through the use of various representations of context and form, such as abstract models, sketches, paper prototypes, mock-ups, and prototypes on different levels of fidelity combined with stepwise descriptions for their use in the gradual development and refinement of design, from the initial broader activities of ideation to the later narrower activities of specification. Using this mix of representations of form and context adds lateral thinking and divergence to structured problem solving, and structure and method to intuition based illumination. Combining technology-centeredness with user-centeredness, architectural analysis with sociological analysis, sketching with mock-ups and prototypes, and ethnography with object-orientation, are examples of specific design methods, which we have investigated in the work presented here. Taking a contextual approach as exemplified by these methods and techniques means that the creative and technical activities gain and maintain a holistic perspective on the design challenge at hand, transcending that of user- or technology-centeredness.

Lesson 6: improving evaluation

In studying the user experience of mobile interaction design, the contextual approach adds improved techniques for systematic assessments under realistic conditions representative of the future use situations and settings to the palette of evaluation methods for interactive mobile systems. This can be done through hybrid methods and techniques that inherit the qualities of control from traditional laboratory-based usability evaluations, and the qualities of ecological validity of ethnographic field studies by, for example, simulating context in artificial settings, or guiding focus and data collection in natural settings. Simulating mobility or the use domain, bringing the system in to the field, and designing a lab that you can take with you, are specific examples of such hybrid methods and techniques, which we have investigated in the work presented here. Taking a contextual approach to the assessment of mobile interaction design puts explicit

emphasis on the importance of making empirical studies as realistic as possible in terms of the settings and situations they are carried out in, while also ensuring that detailed, comparable and generalizeable data is collected. As demonstrated in the empirical studies discussed, it is possible to design evaluations of mobile interaction design that achieve both ecological validity and experimental control.

Lesson 7: artefacts

In building interactive mobile system artefacts, the contextual approach promotes convergence of form and context that explores the use of established and emerging technologies for making close relationships between content, functionality, interaction, system behaviour and the surrounding context. This can be done by building concrete interactive mobile system prototypes that implements different ways of relating their content and functionality to their context, ways of facilitating user interaction with such content and functionality, and ways of making content and functionality respond to contextual changes. Building prototypes that mediate or adapt to context, and do so passively or actively, are examples of such systematic synthesis of new technologies for the design of mobile interactions, which we have investigated in the work presented here. Taking a contextual approach to the implementation of such artefacts encourages the technical construction of a certain type of mobile interaction design where there is an inherently close and explicit relationship between interactive systems, users and their surrounding context. As demonstrated with the interactive prototype systems discussed, this is not simply a matter of making them respond automatically to context, but offers a much wider range of new and interesting opportunities for mobile interaction design.

Lesson 8: understanding

In understanding the user experience of mobile interaction design, the contextual approach promotes a holistic perspective on the interplay between people, interactive systems, and context, seeing it as a whole that is larger than the sum of its individual parts. From a contextual perspective, the user experience of interactive mobile systems is a complex system that cannot be understood well through reductionism alone but also has to be considered in its totality. This can be done by scrutinising the phenomenon through theoretical and conceptual lenses that particularly focus on explaining the relations and interactions between elements in an interactive system rather than on explaining the individual mechanics of these elements. When trying to understand, abstractly, the user experience of a mobile interaction design, the central question is how people create meaning from such artefacts in context. Perceiving meaningful patterns and wholes, interpreting meaning of signs, creating shared meaning through our embodiment in the world, and orchestrating mobile devices by creating meaningful ecosystems are examples of specific holistic perspectives, which we have investigated in the work presented here. Taking a contextual approach to understanding the user experience of mobile interaction design means that the analytical outcomes transcend specific technologies and users, facilitating further research and design at a pace beyond incremental steps from one design to the next.

8. EPILOGUE

Nearing the end of my position summary, there remain some questions unaddressed. I have presented a contextual approach to designing contemporary interactive mobile computer systems, that promotes a designerly way of achieving convergence between form and context through a wholeness sensitive and continually unfolding process of design. The value of this approach and way of thinking has been discussed in relation to other design approaches and illustrated through my contributing research publications. But what are the potential challenges and limitations of such a contextual approach and holistic view? And where do we go from here?

Challenges for a contextual approach

One potential challenge in taking a contextual approach to the interaction design process, rather than a traditional user- or technology-centred one, is that the concept of *context*, and *form-context ensembles,* may appear too abstract and difficult to grasp. In contrast, *users* are entities that we can relatively easy define, identify, study, and simply go and talk to if we don't quite understand them. Similarly, *technology* is a relatively tangible thing in interaction design that we can often simply look at, touch, and try out. The intangibility of entities like context and wholeness make them more difficult to deal with by comparison. If a contextual approach to interaction design is to succeed, we will need to explore it further, and to develop concepts, techniques, and best practices that make it accessible for interaction designers and interaction design researchers to embrace and hence practice contextual and holistic thinking in their work. My own contributions to this included in this thesis are steps in that direction. But they are in no way complete. My hope is that this is something others will find interesting to pursue, and that researchers and practitioners currently grounded in user- or technology-centred design will not see the views that I have presented here as a disparagement against the quality or importance of their work. After all, taking a contextual approach is not a matter of throwing away the legacy of user- or technology-centred design at all. It is a matter of trying to include both of these view-points, equally, and within a broader scope that enables us to transcend them.

Downsides of holism in interaction design

In terms of the downsides of a holistic view on interaction design, an obvious concern is that by focussing on the whole, you might erroneously neglect or ignore important details of the parts. This is a valid concern, and one that is important to keep clear in mind when taking a holistic stance. The kind of holistic thinking that I have promoted in this thesis falls within what Edmonds (1999) calls *pragmatic holism.* Rather than the all-embracing view of a system in *experiential* holism, this is the kind of *non-linear* holism that refers to the phenomenon of emergence in that "when A and B are combined, the resulting C has more properties than what each of the components bring" (Raman 2005). While reductionism may struggle to deal with such phenomena of emergence in complex systems and how individual elements can converge into something very different, holism on the other hand may struggle to deal with identifying and explaining what "lies beneath" a larger whole in a way that enables us to understand it, and possibly reproduce it.

Essentially these concerns put us in the middle of the highly polarised debate about whether reductionism or holism is the better approach for viewing and dealing with the world (see, for example, Edmonds 1999, Raman 2005). I won't go into this debate here, but in my opinion neither of the two are, in their extreme forms, very useful positions to hold as interaction designers or interaction design researchers. What is needed in interaction design are world views that are less dogmatic and more pragmatic, seeking *useful* accounts, models, and understandings of the phenomena in the world that we are interested in designing and designing for. Both reductionism and holism are legitimate and have value in this respect. But they provide us with very different pictures and understanding of the same phenomenon. As described by Raman (2005), like a microscope and a telescope, reductionism and holism are two powerful instruments to explore the world. "Each is relevant and important in its own context. The more we focus on one, the more the other becomes blurred. Thus, reductionism and holism are complementary in the Bohr sense of the term" (Raman 2005), and to get a full picture, we need them both. In the words of Herbert Simon "in the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist" (Simon 1962). Conversely an in-principle holist may at times need to apply reductionist principles when pragmatically useful and not compromising the overall view of the whole.

In mobile interaction design the reductionist view is already strongly present, but the complementary holistic view is not.

Towards digital ecology

The final thing I wish to touch upon are the notions of digital ecosystems and artefact ecologies. As I have discussed in section 2.1 the currently emerging trend within mobile computing is the creation of digital ecosystems where interactive mobile systems and devices are viewed less in isolation and more as parts of larger use contexts or artefact ecologies (see, for example, Jung et al. 2008, Bødker and Klokmose 2011). In my opinion this is an avenue for further research that is particularly interesting, and one that I look forward to engaging with more deeply. As a starting point for this, I believe that the contextual approach on designing mobile interactions presented in this thesis holds potentials for designing digital ecosystems and artefact ecologies. The reason for this is that it already inolves designing for the whole and has a build-in sensitivity for the continual emergence and convergence of form and context that characterises such ecosystems and ecologies. What is still needed though is the further development of a theoretical and conceptual lens through which we can view, address and describe this emerging phenomenon in a way that informs and inspires design and further thinking. This work may find inspiration and traction in some of the conceptually stronger and less technical literature on ubiquitous and pervasive computing that has started to appear in recent years, such as Adam Greenfield's book "Everyware" (2006).

As a way of encapsulating and labeling this work, I suggest using and developing the term *digital ecology.* Ecology is the study of elements making up an ecosystem, and is very generally about understanding the interactions between organisms and their environment. It is inherently holistic and has an interdisciplinary nature, and it is not synonymous with "the environment" or with "environmentalism". Nor is ecological thinking limited to the discipline of biology. For example, "industrial ecology" studies

material and energy flows through networks of industrial processes, and "human ecology" is as interdisciplinary area of research that provides a framework for understanding and researching human social interaction. In a similar fashion, I believe "digital ecology" may be a useful way of describing the study of elements making up digital ecosystems and the holistic understanding of interactions between these elements and their environment[5]. By digital ecology I thereby mean the study of interrelated digital systems (e.g. mobile and pervasive computing) and the processes by which these systems work and interact, and are conceived, emerge, converge, and evolve. It is about understanding the functioning, use and experience of digital ecosystems and digital artefact ecologies around us, and the design processes that create and advance them.

ACKNOWLEDGEMENTS

This work was funded in part by the Danish Technical Research Council, grants No. 26-03-0341 and 26-04-0026, several project and travel grants from The Obel Family Foundation, Aalborg University's Faculty of Engineering and Science, and the Department of Computer Science. I thank all of my co-authors on the included research publications, in particular my primary collaborators and co-authors over the last decade: Jeni Paay, Mikael B. Skov, Steve Howard, Jan Stage, Frank Vetere, Connor Graham, Kenton O'Hara, and Sonja Pedell. Very special thanks to Lars Mathiassen and Steve Howard for feedback and discussions on early drafts of the thesis, to Erik Frøkjær for ongoing fruitful discussions of my work, and to members of the Information Systems group/Centre for Socio-Interactive Design for constructive comments about how to strengthen it. I also thank Ellen Christiansen for introducing me to the works of Christopher Alexander. Finally, I wish to thank my Ph.D. and many Masters students in Human-Computer Interaction over the years, who have contributed to my research through prototype experiments, user experience studies and discussions on mobile interaction design, in particular Dimitrios Raptis, Henrik Sørensen, Rahuvaran Pathmanathan, Claus M. Christensen, Klaus Kjeldsen, Niels Husted, Jacob Nørskov, Kenneth Pedersen, Glen W. Nielsen, Søren Thorup, Michael Vestergaard, Rene Vutborg, Liv Stahl Madsen, Simon Lind Damgaard, Michael Bønnerup, Søren H. Møller, Thulasika Rasenthiran, Anders Christensen, Eva Andersen, and Lars Hedegaard.

5) The term "digital ecology" has elsewhere been used to describe the fusion of virtual and real life forms, or the mix of digital code and environmentalism. These are not related to my suggested use of the term.

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Challenges and opportunities

Chapter 2. A review of mobile interaction design research

Chapter 2

A review of mobile interaction design research

Jesper Kjeldskov and Connor Graham

Abstract. This paper examines and reviews research methods applied within the field of mobile human-computer interaction. The purpose is to provide a snapshot of current practice for studying mobile HCI to identify shortcomings in the way research is conducted and to propose opportunities for future approaches. 102 publications on mobile human-computer interaction research were categorized in a matrix relating their research methods and purpose. The matrix revealed a number of significant trends with a clear bias towards building systems and evaluating them only in laboratory settings, if at all. Also, gaps in the distribution of research approaches and purposes were identified; action research, case studies, field studies and basic research being applied very infrequently. Consequently, we argue that the bias towards building systems and a lack of research for understanding design and use limits the development of cumulative knowledge on mobile human computer interaction. This in turn inhibits future development of the research field as a whole.

1. INTRODUCTION

The study of human computer interaction for mobile devices is a relatively young research field in which commercially successful devices have only been available for less than a decade and leading conferences have only a few years of history. In young research fields there is often a tendency to be highly opportunity and technology driven and to focus primarily on producing *solutions* while reflecting less on methodology. This characterized early computer research and can also be seen in relation to emerging research areas such as virtual and augmented reality. As a research field matures, examining how the research is being conducted and reflecting on the impact of this on the knowledge being produced is necessary in order to be able to understand and influence the future direction of the field. So far, this has not been done consistently within the community

Originally published as Kjeldskov, J. and Graham, C. (2003) A Review of MobileHCI Research Methods. In *Proceedings of Mobile HCI 2003,* Udine, Italy. LNCS (pp. 317-335). Berlin, Springer-Verlag.

of mobile HCI and consequently little knowledge on a methodological level exists about the research field. This analysis and discussion will be borne out by this paper. Inspired by related studies within the field of Information Systems (IS), we aim at evoking more discussion of research methodology in mobile HCI by presenting a snapshot of current research practice within our field, identifying and discussing shortcomings in present research and opportunities for future approaches.

Focus and reflection on research methodology has been a key subject within information system research for decades (see for example Basili et al. 1986; Benbasat 1987; Galliers 1990, Myers 1997, Wynekoop and Conger 1990). Facilitating this discussion, a number of frameworks for describing and categorizing IS-research methods have been developed (see for example Galliers 1990), which could also be relevant in relation to discussions of mobile HCI research. Specifically, we find that the classification of computer-aided software engineering (CASE) research by Wynekoop and Conger (1990) demonstrate a generally usable (and relatively simple) approach to informing the discussion of research methods applied within a given area. Wynekoop and Conger (1990) reviewed and classified 40 IS-research papers in a two-dimensional matrix relating research methods and research purpose, providing a picture of the research field facilitating discussion of current research practice. In this paper we replicate elements from this study by applying its overall approach to the field of mobile HCI. In section 2 and 3 we present the categories of research methods and research purposes used in our classification. In section 4 we describe the conducted review of Mobile HCI research papers and present a matrix describing the resulting classification. Trends highlighted by this matrix are then discussed in section 5 and in sections 6 and 7 we indicate limitations, conclude our study and point out paths for further work.

2. RESEARCH METHODS

Defining and especially differentiating research methods can be a challenge. Definitions are sometimes vague and often different aspects of different methods overlap. As the purpose of this paper is not to discuss definitions of research methods as such, we have chosen to apply eight definitions extracted from Wynekoop and Conger (1990) with supplementary input from general references on research methodology in information systems (Lewis 1985; Myers 1997; Rapoport 1970; Yin 1994). Knowing that these definitions may themselves be objects for disagreement, we refer to Wynekoop and Conger (1990) and Galliers (1990) for further discussion of the definitions.

In this section, we present and review the eight research methods used in our classification of mobile HCI research. For each method, strengths and weaknesses are identified as well as primary uses and possible application in mobile HCI research. This discussion is summarized in table 1. As an overall categorization, we group the eight research methods according to Benbasat's (1985) categories of *natural, artificial* and *environment independent* settings.

Table 1. Summary of research methods, extracted from Wynekoop and Conger (1990)

	Method	Strengths	Weaknesses	Use
Natural setting	Case studies	Natural settings Rich data	Time demanding Limited generalizability	Descriptions, explanations, developing hypothesis
	Field studies	Natural Settings Replicable	Difficult data collection Unknown sample bias	Studying current practice Evaluating new practices
	Action research	First hand experience Applying theory to practice	Ethics, bias, time Unknown generalizability	Generate hypothesis/theory Testing theories/hypothesis
Artificial setting	Laboratory experiments	Control of variables Replicable	Context insensitive No variable manipulation	Controlled experiments Theory/product testing
Environment independent setting	Survey research	Easy, low cost Can reduce sample bias	Context insensitive No variable manipulation	Collecting descriptive data from large samples
	Applied research	The goal is a product which may be evaluated	May need further design to make product general	Product development, testing hypothesis/concepts
	Basic research	No restrictions on solutions Solve new problems	Costly, time demanding May produce no solution	Theory building
	Normative writings	Insight into firsthand experience	Opinions may influence outcome	Descriptions of practice, building frameworks

2.1. Case Studies

Yin (1994) defines a case study as "an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Thus case studies are often intensive empirical studies of small size entities such as groups, organizations, individuals, systems or tools with the researcher distinct from the phenomena being studied (Wynekoop and Conger 1990). When conducting case studies, data is typically collected by a combination of various qualitative and quantitative means such as observations, interviews and questionnaires etc. with little experimental or statistical control enforced. The data collected is grounded in natural settings, typically very rich and sometimes contradictory or inconsistent, thus often resulting in complicated analysis. Case studies are particularly well suited for research focusing on describing and explaining a specific phenomenon and for developing hypothesis or theory through, for example, applying grounded-theory approaches. However, case studies are very time demanding and generalizing findings can be difficult.

Since mobile HCI is a relatively young research area, case studies could be used to provide rich data explaining phenomena involving mobility or the use of mobile devices in context.

2.2. Field Studies

Generally, field studies are characterized by taking place in "the real world" as opposed to in a laboratory setting. Field studies cover a range of qualitative and quantitative approaches from *ethnographic* studies of phenomena in their social and cultural context inspired by the discipline of social and cultural anthropology (Lewis 1985) to field *experiments* in which a number of independent variables are manipulated (Wynekoop and Conger 1990).

Ethnographic field studies are characterized by researchers spending significant amounts of time in the field and, to some extent, immersing themselves into the environment they study. Typically, data is gathered through observations and/or interviews and the phenomena studied are placed in a social and cultural context. The major advantage of ethnographic field studies is the generation of large amounts of rich and grounded data in relatively short time. The major disadvantages are unknown biases and no guarantee of collected data being representative.

While ethnographic field studies are non-experimental, field experiments are characterized by manipulation of a number of independent variables to observe the influence on dependant variables in a natural setting. The major advantages of field experiments are increased realism and increased control in comparison to ethnographic field studies and support for studying complex situated interactions and processes. Disadvantages include limited control of experiments and complicated data collection compared to, for example, experiments in laboratory settings. Furthermore, as experimental manipulation increases, realism typically decreases.

In relation to mobile HCI research, field studies could be applied for either informing design for or understanding of mobility by ethnographic studies of current practice or for evaluating design or theory by conducting experiments in realistic use settings.

2.3. Action Research

Originating from the social sciences, action research is a well-established research method through which researchers not only apply scientific knowledge to an object of study, but also add to the body of scientific knowledge through that study, thus differentiating action research from applied science or research (Myers 1997). Conducting action research, the researcher participates in the intervention of the activity or phenomenon being studied while at the same time evaluating the results (Wynekoop and Conger 1990). More specifically, Rapoport (1970) defines action research as aiming "to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework".

The advantage of action research is the very close relationship between researchers and the phenomena of interest. This facilitates first-hand insight, limits researcher influence on subjects being studied and supports a prosperous way of applying theory to practice and evaluating its outcome. However, action research is very time consuming, and since the researcher takes part in the phenomena studied remaining objective can be difficult. Also, when participating in the intervention of an activity or phenomenon, considerations emerge concerning if it is ethically acceptable for a researcher, for example, to conceal knowledge of particular approaches having better effects than others. Finally, the outcome of this research can be difficult to generalize.

In relation to mobile HCI research, action research could be used for extending field or case studies by researchers participating actively in real world activities involving mobility, introducing different solutions or theories "on-the-fly" as well as evaluating their effects and/or validity.

2.4. Laboratory Experiments

In contrast to field studies, laboratory studies are characterized by taking place in a controlled environment created for the purpose of research. Thus laboratory experiments do not necessarily have to take place in dedicated "laboratories" as such but can be conducted in various controlled environments such as in an office (Tang et al 2001), in a hallway (Bohnenberger et al. 2002) or in a simulator (Kjeldskov and Skov 2003). Laboratory experiments facilitate various types of data being collected using different experimental methods depending on the style of subsequent analysis desired. While traditional quantitative measurements of factors such as error rate and task completion times collected through, for example, cognitive walkthrough methods are suitable for statistical methods of analysis, using more qualitative approaches such as heuristic evaluation or think-aloud protocols during the conduct of experimental tasks also produces results suitable for analysis.

The major advantages of laboratory studies are the opportunity to focus on specific phenomena of interest and a large degree of experimental control in terms of manipulation of variables before and during the experiment through for example assignment of test subjects and exposure to different treatment variables (Wynekoop and Conger 1990). Also, laboratory experiments are typically highly replicable and facilitate good data collection. Disadvantages include limited relation to the real world and an unknown level of generalizability of results outside laboratory settings.

In mobile HCI research, laboratory experiments are suitable for evaluating design ideas, specific products or theories about design and user interaction in controlled environments with little or no interference from the real world.

2.5. Survey research

Surveys usually inform research by providing information from a known sample of people gathered through various systematic techniques such as questionnaires and interviews. Using surveys, data is gathered directly from selected respondents and it is assumed that these are independent of their environment (Wynekoop and Conger 1990). Typically, data from questionnaire surveys is collected without researcher intervention and is analyzed quantitatively while data from interview surveys are analyzed qualitatively.

The major advantages of surveys are that they facilitate large amounts of data to be gathered with relatively little effort, supporting broad generalization of results. Also a high level of control regarding sample subjects makes reduction of bias possible thus increasing validity. However, surveys suffer from providing only snapshots of studied phenomena and rely highly on the subjective views of respondents.

In mobile HCI research, surveys could, for example, facilitate generalizable information being gathered about user needs and requirements for understanding a phenomenon, building theory or developing systems. Also, surveys could be used for gathering data about the user experience of specific products or designs for evaluation purposes.

2.6. Applied Research

According to Wynekoop and Conger (1990) applied research, builds on trial and error on the basis of the researchers capabilities of reasoning through *intuition, experience, deduction* and *induction.* Typically the desired goal or outcome of the research process is known in terms of requirements on some level of abstraction, but methods or techniques for accomplishing this outcome are unknown and thus sought through applying potentially relevant research. The advantages of applied research is that it is very goal directed and (typically) results in some kind of product being produced, which can be evaluated against the initial goals. The major disadvantages of applied research are that initial solutions may be very limited and not generalizable and that appropriate solutions for accomplishing the desired outcome may not be produced at all.

In mobile HCI research, applied research is relevant in relation to design and implementation of systems, interfaces and techniques, which meet certain requirements for performance, user interaction, user satisfaction etc.

2.7. Basic Research

Doing basic research, researchers develop new theories or study well-known problems to which neither specific solutions nor methods for accomplishing solutions are known (Wynekoop and Conger 1990). Like applied research, the approach of basic research is trial and error based relying on the competences of the researcher. The major advantage of basic research is the openness of the research facilitated both in terms of approaches and time, allowing a high level of creativity in the search for methods and solutions. However, basic research, like applied research, can be very time consuming and there is no guarantee of any solution eventually being produced.

In relation to mobile HCI, basic research may be applied to the development of theoretical frameworks for, for example, understanding basic issues of mobility or for identifying new problems and possible solutions related to human-computer interaction while being mobile.

2.8. Normative Writings

In order to include the significant body of so-called "non-research" writings about phenomena of interests in their classification of research methods, Wynekoop and Conger (1990) suggests the category of *normative writings,* covering concept development writings, presentation of "truth" and Benbasat's (1987) category of "application descriptions". While concept development writings organize ideas in order to stimulate and indicate directions for future research, such as the case of this paper, normative writings belonging to the "truth" category present ideas, concepts and suggestions, which seem intuitively correct but are not based on theory or research. Application descriptions are defined as "narratives written by practitioners" (Wynekoop and Conger 1990), describing subjective views on a situation and what worked for them in that particular situation. The primary advantage of normative writings is that they require little effort to produce compared to presenting theoretical concepts. Disadvantages include limited theoretical and methodological reflection and limited generalizability.

In mobile HCI, normative writings describing designs and processes that worked well or did not prove successful may be useful for inspiring future research or design.

3. RESEARCH PURPOSE

Research methods as discussed above and research *purpose* are typically closely related but not necessarily determined by one another. Like Wynekoop and Conger (1990) we thus use the second dimension of our matrix for classifying mobile HCI research to describe research purpose. Populating the categories this dimension we borrow the categories and definitions of research purposes originally proposed by Basili et al. (1986) and also used by Wynekoop and Conger (1990). These are briefly defined below.

Understanding is the purpose of research focusing on finding the meaning of studied phenomena through e.g. frameworks or theories developed from collected data.

Engineering is defined as the purpose of research focused towards developing new systems or parts of systems such as e.g. an interaction technique for mobile phones.

Re-engineering describes the purpose of research focusing on improving existing systems by redeveloping them such as e.g. adapting a web browser to a small display.

Evaluating is the purpose of research assessing or validating products, theories or methods e.g. the usability of a specific mobile device design or a theory of interaction.

Describing finally refers to research focusing on defining desirable properties of products e.g. a mobile system.

4. CLASSIFICATION OF MOBILE HCI RESEARCH

In this section we present a classification of selected mobile human-computer interaction research papers in relation to the research methods and purposes discussed above.

A total of 102 conference and journal papers were classified in relation to the described categories of research purpose and research methods applied. These papers constitute all publications related to mobile human-computer interaction between 2000 and 2002 in the following top-level conference proceeding series and journals:

- Conference on Computer-Human Interaction, CHI, ACM
- Conference on Advanced Visual Interfaces, AVI, ACM
- Conference on User Interface Software and Technology, UIST, ACM
- Conference on Computer-Supported Cooperative Work, CSCW, ACM
- Symposium on Mobile Human-Computer Interaction, Mobile HCI
- Symposium on Designing Interactive Systems, DIS, ACM
- Transactions on Computer-Human Interaction, TOCHI, ACM
- Journal of Personal and Ubiquitous Computing, Springer-Verlag

While other conferences and journals exist, presenting interesting research on mobile human-computer interaction, we found that the listed conferences and journals provided a solid and adequately representative base for this study given the number of publications on the topic and the general level of the reviewing processes for these conferences and journals.

The 102 papers specifically focusing on mobile human-computer interaction were identified by thoroughly reading through abstracts (and sometimes introductions) of all publications between 2000 and 2002 in the listed conference proceeding series and journals. A paper was selected for the study if it was in any way related to mobile devices and human-computer interaction. Thus a paper would be omitted if it focused only on mobile network protocol design or did not involve any aspect of mobility of users or systems. All papers were printed, numbered, read through and classified over a period of two weeks by the first author of this paper with particular focus on identifying the purpose of the presented work and the research methods applied in achieving this. The classification is shown in table 2 below.

To ensure consistency, the initial classification of the papers was evaluated by scanning through all the papers a second time on a single day. To ensure validity, the second author of this paper subsequently evaluated the classification by blindly classifying 20 randomly selected papers. As this resulted in a number of disparities, all 102 papers were discussed and classified one by one in collaboration between the two authors.

While in the review presented in Wynekoop and Conger (1990) each paper is only attributed to one research method and purpose, this was not possible with all of the papers on mobile human-computer interaction. Some of the reviewed papers clearly employed more than one research method and had multiple purposes. A common example of this would be papers presenting a system engineered by applying research and subsequently evaluated in a laboratory. Consequently, such papers were given multiple classifications and appear more than once in table 2 above. As a consequence of multiple research methods and purposes in the same paper, aggregate percentages will sometimes amount to more than 100%.

Table 2 shows that 55% of mobile HCI research falls within the applied category (56 of 102 papers). The secondly most used method is laboratory experiments being applied in 31% of the research (32 of 102 papers). 20% of the papers report from field studies and 8% report from survey studies while 7% are normative writings and 6% report from case studies. Only 3 papers were classified as basic research and no entries were found for action research. This distribution shows a clear bias towards environment independent and artificial setting research in the form of applied and laboratory based approaches at the expense of natural setting research focusing on real use and basic and action research generating theory and refining it in practice.

Looking at the research purpose, 51% of mobile HCI research is done for engineering with additional 10% done for re-engineering. Thus in total, 61% of the research reported involves building systems. 41% of the papers involve evaluation, of which 71% is done through laboratory experiments 19% through field experiments and the remaining 10% through surveys. Research for understanding mobile HCI accounts for 18% of the papers, of which 22% reports from the use of surveys and 22% from field studies. Describing different aspects of mobile HCI accounts for 10% of the research, of which 50% are in the form of normative writings. Thus within mobile HCI research there is a clear tendency towards building systems and if evaluating them, doing so in laboratory settings. Understanding and learning from the design and real use of systems

is less prioritized, limiting the generation of a cumulative body of knowledge on mobile human-computer interaction.

Table 2. Classification of mobile human-computer interaction research. Numbers refer to indexes in the appendix of reviewed mobile HCI research papers bibliography

Research purpose \ Research Method	Case studies	Field studies	Action research	Lab experiment	Survey research	Applied research	Basic research	Normative writings
Understand	10, 11, 51	67, 68, 69, 101		91	14, 25, 53, 72	43	1, 21, 32	16, 20
Engineer	24, 49	3, 65, 71, 85, 94				2, 4, 9, 12, 17, 18, 19, 23, 27, 28, 29, 33, 34, 36, 38, 39, 41, 45, 46, 48, 50, 52, 57, 58, 59, 60, 64, 70, 73, 74, 76, 77, 78, 79, 81, 83, 84, 86, 89, 90, 92, 93, 95, 97, 98		
Re-engineer	22	6, 9, 41, 63, 71, 81, 85, 89				7, 8, 31, 55, 63, 75, 80, 100, 102		
Evaluate				4, 5, 6, 7, 8, 9, 12, 13, 18, 22, 30, 40, 42, 44, 49, 50, 55, 56, 58, 60, 61, 66, 75, 77, 82, 90, 94, 97, 98, 99	26, 33, 64, 93			
Describe		47, 62, 96		47		35		15, 37, 54, 87, 88

Of the 56 papers applying research, 96% do so for the purpose of engineering or re-engineering. Thus in total, these two cells in the matrix account for more than 50% of the mobile HCI research classified. Of the 32 papers in the laboratory experiment category, 94% use this method for evaluation purposes. Of the 20 papers reporting from field studies, 40% use this method for evaluation purpose while 25% use it for engineering. 20% (4 papers) report from field studies for the purpose of understanding. Thus when building systems within mobile HCI research, there is a clear tendency to do so primarily by trial and error and a lesser tendency to do so based on actual user studies. Also, controlled environments are used primarily for product evaluation purposes. Field studies are only applied to inform the design of new systems to a limited extend.

Of the 45 papers reporting applied research with the purpose of engineering systems, only 37% (17 papers) *also* report evaluating the produced solutions. 61% of these evaluations are done through laboratory experiments, 22% through field studies and the remaining 17% by surveys. Of the 9 papers reporting the *re-engineering* of systems, 56% also report evaluations of these systems. 80% of these are through laboratory experiments and 20% through field studies. Thus when building new systems, there

is a tendency towards *not* evaluating them while when subsequently *re-building* them, evaluation is more prevalent. When evaluating engineered or re-engineered systems, there is a large bias towards applying laboratory-based approaches.

5. DISCUSSION

Table 2 reveals a lack of focus on real use contexts in relation to engineering and evaluating mobile systems as well as limited construction and use of theory. While field studies *are* being done, natural setting research is not prevalent. One reason for this may be that applied research and laboratory experiments are simply easier to conduct and manage than field studies, case studies and action research. Another reason may be that mobile HCI has strong roots in computer science and human-computer interaction. These fields collectively have a strong bias towards engineering and evaluating systems, with input from fields such as ethnography only recently emerging.

Reflecting further on table 2, a number of features seem to characterize the field of mobile human-computer interaction. Firstly, given the prevalent applied approach to engineering it seems assumed that we already know what to build and which specific problems to overcome such as limited screen real estate, limited means for interaction, dynamic use-contexts and limited network bandwidth. As only a little research actually addresses the question of what is useful and what is perceived problematic from a user-perspective and as a qualitative review of the classified papers reveal that evaluations are often focused on functionality rather than contextual issues, it is difficult to set aside this assumption and identify and face more fundamental challenges to mobile human-computer interaction. Secondly, given the limited focus on real-world studies it seems that the real contexts are not actually important for the mobile system we build and use and that mobile computer systems are a generically applicable solution. The view that building and evaluating systems by trial and error is better than grounding engineering, evaluation and theory in user-based studies weakens research in mobile HCI. Thirdly, given the fact that only few studies are based on a methodological foundation, it seems assumed that methodology matters very little in mobile HCI research. This supposition is problematic as the choice of methods clearly has influence on the results subsequently produced (Myers 1997). From a cognitive psychology perspective, for example, problem solving by applied research is viewed as a rather poor method as it demands huge efforts by researchers that often "translate into poor performance because they require search of a large space of possibilities" (Wynekoop and Conger 1990).

The distribution of research methods and purposes shown in table 2 offers a number of opportunities in the area of mobile HCI. Firstly, the fact that field studies are mostly being used for the purpose of evaluation presents the opportunity to use this method to explore use context and user needs to promote understanding. Field studies could assist with the translation of needs into new designs and the re-engineering of existing designs. Mobility is very difficult to emulate in a laboratory setting, as is the dynamism of changing context. Field studies offer the ideal opportunity for the study of rich real-world use cases. Learning from other disciplines that have struggled with the study of similar "slippery" phenomena, such as ethnography in this regard could provide important insight. The lack of survey and case study research also presents

an opportunity. Information Systems uses these approaches widely, with the former research method often being used to collect large amounts of data from, for example, actual end-users of a system. In addition this approach offers a good opportunity to study the use of systems in the hands of a large segment of the population, enabling wider reaching generalizations. Case studies within mobile HCI could increase learning from existing implemented systems within real-world contexts, for example mobile systems and infrastructure within organizations. Such case studies would enable the close scrutiny of pre-defined phenomena in fixed contexts, which could then be used to enrich the collective knowledge in the discipline and to enable key issues to be described and understood. The issues generated could then be used to generate hypotheses to propagate further research. The limited use of action research points to both the lack of a well-established body of theoretical research within the discipline and the unwillingness to implement mobile systems which are uncertain to succeed and take a long time to evaluate and implement. This is perhaps not surprising, given the current cost of such technology and the associated implementation overhead. Nonetheless, this is, again, an opportunity to develop knowledge in the discipline through practice and evaluation. Finally, the lack of basic research means that opportunities exist for the development of theoretical frameworks to promote description and understanding. In addition, the applicability of theories from other disciplines to mobile HCI can be examined through basic and action research.

6. LIMITATIONS

The presented review of research methods has a number of limitations. First of all, the categories of research methods can be criticized for being vague and overlapping. Thus for example, case studies are often done in the field but it is unclear how this method differs from field studies. If a case study were, on the other hand, conduced in a controlled environment, how would it be different from a laboratory experiment? Furthermore, it can be discussed whether the eight categories of methods belong to the same level of abstraction or if some categories could be subordinated others. Combined with the fact that many research papers provide only little information about method, it can be difficult to decide which category a specific paper belongs to. Thus the presented study relies on the researchers comprehension of the categories and ability to make a qualified judgment on the basis of sometimes scarce information. Also, it can, of course, be questioned if the selected papers are representative and to what extent activities within a given area are actually reflected through publications.

7. CONCLUSIONS

In this paper we have examined and reviewed research methods within the field of mobile HCI through classifying 102 research papers. We have identified a number of significant trends in research purpose and methods with a clear bias towards engineering systems using applied approaches and, if evaluating them, doing so in laboratory settings. In addition we have found that research methods examining phenomena in context such as case studies are not widely used. These findings present a number of opportunities for further research suggesting the need for a change of emphasis within mobile HCI.

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APPENDIX: REVIEWED MOBILE HCI RESEARCH PAPERS, 2000-2002

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Part I

Studying and analysing

Chapter 3. Physical context

Chapter 4. Social context

Chapter 5. Personal context

Chapter 6. Work context

STUDYING AND ANALYSING

Part I addresses the question *how can we study, analyse and understand aspects of context relevant for mobile interaction design?* In order to do contextual interaction design we need to understand what context is, for a particular design task. What dimensions of context are important, what role they play, how they interact and influence each other, etc. Four of my own contributions to this are included in chapters 3-6. These chapters each address and explore a particular dimension of context for mobile interaction design: physical, social, personal and work, by specifically investigating four contextual entities: places and surroundings, people and interactions, families and relationships, and tasks and coordination.

Physical context

Chapter 3 investigates physical context. The chapter presents a field study and architectural analysis of a concrete urban environment, Federation Square in Melbourne, Australia. The study was conducted by combining empirical and analytical methods from architecture and city planning to survey, model and represent prominent architectural and informational aspects of a built environment such as districts, buildings, structures and signage. The result of the study is a descriptive framework summarizing the architectural and informational properties of a built environment. The use of such understanding in mobile interaction design is illustrated through a location-based mobile guide.

Social context

Chapter 4 investigates social context. The chapter presents a field study and sociological analysis of small groups of friends socializing "out on the town" in the same urban area as investigated in chapter 3. The study combined rapid ethnography, contextual interviews, and grounded analysis, and was guided conceptually by a typology for situated interactions. This resulted in a conceptual framework encapsulating and describing the interplay between people, activity and places during situated social interactions in an urban environment structured around the three key concepts of knowledge, situation and motivation. The use of such understanding in the design of mobile interactions is illustrated through a context-aware mobile guide representing and adapting to social context.

Personal context

Chapter 5 investigates personal context. The chapter distils eight dimensions of intimacy from the literature, and presents a longitudinal field study of technology-mediated intimacy and strong-tie relationships with six families in Melbourne, Australia. In order to minimize researcher intervention in peoples' private lives, the study deployed the "auto-ethnographic" approach of cultural probes in combination with contextual interviews. The outcome of the study is a thematic understanding of what constitutes intimacy and how interactive systems are appropriated and used within intimate relationships. The use of such insight in mobile interaction design is illustrated through three early design ideas for technologies supporting intimacy.

Work context

Chapter 6 investigates work context. The chapter presents an ethnographic field study of communication on board large container vessels while manoeuvring inside harbour basins, and a simulator study of prototype technology in use. The outcome of the study is a detailed understanding of communication and coordination in the work context, based on a model of conversation for action. From this understanding it is possible to model communication flow in distributed work and use this to facilitate persistency in communication. This is demonstrated through the design of a mobile text-based communication system.

Chapter 3

Physical context

Jeni Paay and Jesper Kjeldskov

Abstract. The research presented in this paper aims to inform interface design for mobile guides by understanding and modelling the built environments in which the guide will be used. This is important because research into the use of mobile guides has shown that people have a strong ability to make sense of the physical space in which they are situated and make use of this when using mobile guides. Based on a field study and architectural analysis of the recently built Federation Square in Melbourne, Australia, we present a descriptive framework, MIRANDA, which provides a summarized abstraction of the fundamental architectural and informational features of a built environment. The use of this descriptive framework in HCI design for mobile guides is exemplified through the design of a mobile guide system for Federation Square that was informed by the identified architectural characteristics. On the basis of the field study and example design, we argue that mobile guides interface design can benefit from making use of 'knowledge-in-the-world' by streamlining and indexing information and functionality to physical information cues implicit in the built environment surrounding the user.

1. INTRODUCTION

Mobile guides are increasingly becoming a part of the way we operate in the physical world, and studies suggest that one of the major applications of future mobile information technology will be to digitally enhance user activities by giving them access to contextually adopted information through such guides. Hence the design of mobile guides has received considerable attention over the last decade within the field of HCI (see e.g. Abowd et al. 1996, Cheverst et al. 2000, Cheverst et al. 2002, Pospischil et al. 2002). The HCI research literature indicates a broad spectrum of different application areas for mobile guides. Mobile city guides provide the user with maps and other relevant information such as the location of restaurants, public offices, tourist sites etc. adapted to the user's location (e.g. Cheverst et al. 2000, Cheverst et al. 2002, Pospischil et al.

Originally published as Paay, J. and Kjeldskov, J. (2005) Understanding and Modelling the Built Environment for Mobile Guide Interface Design. *Behaviour and Information Technology,* 24(1), 21-35.

2002, Iacucci et al. 2003, Schmidt-Belz and Poslad 2003, Laakso et al. 2003). Mobile guides for specific tourist-sites provide users with the opportunity to follow guided tours or access additional information about the site being visited (e.g. Hermann and Heidmann 2002, Bornträger and Cheverst 2003, Bornträger et al. 2003) and mobile museum guides provide additional information about the specific items on display (e.g. Aoki and Woodruff 2000, Opperman and Specht 2000, Rocchi et al. 2003). Other mobile guide systems support the user's social or personal life, such as mobile personal guides and event planners keeping track of friends and upcoming social events (e.g. Fithian et al. 2003, Kolari and Virtanen 2003, Paulos and Goodman 2004) or mobile shopping assistants keeping track of shopping lists and informing the users about special offers within their vicinity (e.g. Randell and Muller 2000, Bohnenberger et al. 2002). Assisting people commuting and travelling, mobile navigation guides provide route planning information and directions for way-finding (e.g. Holland and Morse 2001, Chincholle et al. 2002, Kulju and Kaasinen 2002) and mobile travel planners keep track of users' itineraries, upcoming meetings etc. (e.g. Ricci et al. 2002, Kjeldskov et al. 2003).

Many of these mobile guide systems involve the user being situated in the built environment of a public space. Yet only a few references have investigated the challenges imposed and opportunities offered by the use of mobile guide systems in the context of buildings and other architectural structures in urban spaces. Exceptions include Vainio et al. (2002) who study navigation and way finding supported by a 3D model-based mobile city guide with clear architectural features such as landmarks, Kulju and Kaasinen (2002) who compare the use of photographs and semi-realistic 3D models augmented with textual information on mobile guides for supporting the user's experience of a physical space, and Laakso et al. (2003) who study the use of realistic 3D maps with topological as well as architectural features as a planning and navigational aid for leisure boat tourists at sea and in the cities they visit. These studies show that people often have a strong ability to make sense of the physical space in which they are situated and typically make extensive use of this when using mobile guides in a built environment. Consequently, it is argued that the use of mobile guides for navigation, way finding, etc. in environments with distinct architectural or other physical features (such as landmarks, noticeable physical structures or special topology) can benefit from taking these features into account by, for example, simply including visual representations of them using street perspective or bird's-eye views (Vainio et al. 2002, Laakso et al. 2003, Nakanishi et al. 2004). However, in order to exploit the user's ability to make sense of architectural features in their physical surroundings in HCI design for mobile guides, we need to better understand the role of the user's physical environment in defining their context and the contribution of existing information embedded into that environment to people's experience of it (Agre 2001, Bradley and Dunlop 2002, Tamminen et al. 2003). Also, we need to learn how to make a clear connection between the user's physical surroundings and the information presented on their mobile guide (Dix et al. 2000, Persson et al. 2002). So far, systematic methods for gathering, analyzing and understanding the properties of a built environment that help define the user's physical context, and appropriate analytical abstractions suitable for informing interaction design on the basis of this, have not yet been developed.

1.1. Indexicality: relating interfaces to their context

An interesting approach to making a clearer relation between mobile device interfaces and the user's context is to apply the idea of indexicality. Indexicality is a concept drawn from semiotics describing the relation between information representations and the context in which an interpreter (user) perceives them. Semiotics operates with three types of representations: symbolic (conventional), iconic (similarity) and indexical (material/causal). Symbols and icons are ways of representing information independent of context like e.g. text and graphical illustrations. Indexes, on the other hand, are ways of representing information with a strong relation to, for example, their spatial and/or temporal context exploiting information present in the interpreter's surroundings. Thus, indexical representations are highly context-specific and only make sense in particular situations; at a specific time, in a specific location, in relation to a specific activity, to specific people, etc. As an example, signposts and information boards are typically highly indexical in the sense that their meaning is tied to a specific location. By locating information in time and space, symbolic and iconic representations can be converted into temporal and spatial indexical representations (Andersen 2001). As shown by Kjeldskov (2002) increasing the level indexicality typically results in a significant reduction of required symbolic and iconic representations.

The concept of indexicality has previously been applied to the design of mobile guide interfaces (Kjeldskov 2002, Graham and Kjeldskov 2003, Kjeldskov et al. 2003) in order to streamline the information and functionality delivered to the user. The idea of applying indexicality to interface design for mobile guides is that if information and functionality on a mobile guide can be indexed to the user's context, then information already provided by the context becomes implicit and does not need to be displayed by the system. Hence, the user's environment becomes a vital part of the interface. This way of making use of 'knowledge-in-the-world' (Norman 1990) allows the limited screen real estate of mobile guides to be optimized to contain only the most vital content and the required user interaction with the mobile guide to be reduced. As a simplified example of this, an indexical mobile guide for patrons entering a cinema complex could be made temporally and spatially indexical by taking into account the time and location of the user, providing only information about the upcoming movies playing within a limited frame of time (temporal indexicality) in that specific cinema (spatial indexicality) (Kjeldskov 2002).

In the studies mentioned above, the mobile guide interface designs only explored temporal and spatial indexicality. However, the idea of indexical interfaces could also be broadened to exploit other aspects of the user's context. In addition to time and location, for example, factors such as existing information in our surroundings, the features of the built environment itself and the use of that environment by other people also play an important role in the context surrounding a mobile user (Paay 2003), and may also be indexed to in a mobile guide.

Relying heavily on the user's knowledge about, for instance, when, where and why they are situated, successful design of indexical interfaces for mobile guides, require that HCI designers have a strong understanding of the aspects of the user's context that they are indexing to. Hence, in order to include indexes to the built environment

in the design of a mobile guide, the features of the built environment contributing to the user-experience of the physical space in which it will be used, needs to be analyzed and modelled in a way that extracts the essence of the place and provides an overview. Information embedded into the built environment and carrying parts of its meaning through its architectural features needs to be identified and proposals for how this can be applied to mobile guide design needs to be developed and evaluated.

This paper contributes to this discussion by presenting 1) a possible approach to enquiring into the features of a built environment informed by theories and methods derived from architecture, 2) a method for creating a descriptive abstraction on the basis of the field data, and 3) an example of how this abstraction can be used to inform the design of a mobile guide prototype. In section 2, we present and discuss the architectural theories and methods used in the study. In section 3, we report from a field study into the architectural and informational properties of a specific built environment, Federation Square in Melbourne, Australia. The idea and early results from this study are described by Paay (2002). The outcome of the field study is presented in the form of a descriptive framework for modelling and understanding the built environment called MIRANDA, which captures positive and negative architectural and informational properties of a physical space. In section 4, the use of this descriptive framework in HCI design for mobile guides is exemplified through the design of a mobile guide system for Federation Square, in which the interface is indexed to the built environment by exploiting information already implicitly present in the user's physical surroundings. Finally, section 5 concludes on our work and outlines our present and future directions of research.

2. ANALYZING THE BUILT ENVIRONMENT

Architectural design has a history of incorporation of social theories and user needs into design methods. Of special interest, Urban Planner, Kevin Lynch (1960) and Architect, Christopher Alexander (Alexander et al. 1977) both modelled built environments, specifically cities, with regard to the people that inhabit those places, hence implicitly including the users in their analysis of physical space.

Lynch (1960) developed a method for visual analysis of city precincts through descriptions of key aspects of the space held by people as they navigate and orient themselves within city precincts. This was done by diagramming the interplay of visible elements in the environment that contribute to a person's environmental image of a place. His purpose was to develop ideas and methods, rather than to prove facts in a final and determinate way. The method proved successful at assisting in the analysis of types of elements of a city, how they are put together, and what makes for strong identity. It also proved to be a useful technique for predicting the probable public image of that city. Lynch documented this technique for describing and understanding key aspects of the environmental image of space held by people as they navigate and orient themselves within city precincts and noted that it would be interesting to apply this method to an environment of a different scale. To understand the role of environmental images of cities in the lives of those who inhabit them, Lynch carried out two basic analyses. Firstly, interviews were conducted with people who either lived or worked in that area. The city dwellers image of the city was elicited from them using interview techniques which

included asking participants to describe features of the city from memory, asking them to draw sketches of the city, and having them make imaginary trips to destinations within the city precinct. Secondly, a field reconnaissance was done by an architecturally trained observer, who mapped the presence of various elements of the physical environment, using categories that had proven significant in analysis of earlier pilot interviews: districts, landmarks, nodes, edges and paths. The observer made subjective judgments based on the immediate appearance of these elements in the field and about their visible contribution to the image of the city, which resulted in maps representing the visual form of a city in respect to these five elements. These maps were then compared to those maps derived from consensus information collected in the verbal interviews and the sketch maps made by the inhabitants to draw conclusions about 'imageability' of built environments.

Alexander et al. (1977) empirically investigated the interplay between architectural space and its inhabitants and identified architectural design problems in context and their impact on inhabitants of that environment. Drawn from observations of historical solutions to common design problems he created a method of analyzing aspects of the built environment and generated a 'checklist' of plausible solutions for design. This checklist was constituted by a collection of 253 hierarchically ordered patterns making up a 'Pattern Language' (Alexander et al. 1977) that begins with patterns defining towns and communities, through the design of individual buildings, down to the detailed design of building elements. The pattern language provides a framework for solutions to these common design problems. Each pattern describes the field of physical and social relationships required to solve a design problem in its stated context. These patterns in themselves are a form of composite pictures including: photographs, sketches, descriptive explanations detailing the context for the pattern, its relationship to parent patterns, a description of the problem, the empirical background of the pattern, evidence for its validity, and the design solution.

The methods of Lynch (1960) and Alexander et al. (1977) have not only proven their value within architecture, but have also demonstrated usefulness in HCI research in analyzing the interplay between architectural, informational and social space with the purpose of designing computerized information systems.

The work of Lynch (1960) is often referenced in relation to the design of computer systems supporting orientation and navigation in complex virtual information spaces, virtual environments and in the real world, and is claimed to be one of the most influential and useful pieces of research on spatial orientation and navigation for interaction designers (see e.g. Sparacino et al. 2000). Information City (Dieberger and Frank, 1998) is an ontology of spaces and connections based on Lynch's five major elements developed to support navigation in large information spaces where a spatial metaphor supports a user's sense of orientation by the use of recognizable landmarks. Similarly, Sparacino et al. (2000) present a 3D web browser using an urban-like information landscape following the guidelines proposed by Lynch (1960) to fetch and represent information from the web. Supporting navigation in virtual reality, Ingram and Benford (1996) apply urban planning principles to the design of virtual environments using Lynch's work to improve the navigation of a virtual environment including districts, landmarks, paths, nodes

and edges. Similarly, Vinson (1999) proposes a series of guidelines for how designers can create and place landmarks in virtual environments for supporting navigation and orientation. Informing the design of a mobile guide system, Kulju and Kaasinen (2002) draw on the work of Lynch (1960) to include landmarks in a 3D city model on a mobile device and augment them with additional textual information to optimize spatial orientation.

The work of Alexander (Alexander et al. 1977) has been successfully applied within various areas of computing; from object-oriented software design (e.g. Gamma 1996) to human-computer interaction (e.g. Tidwell 1999, Borchers 2001). Inspired by, among others, Alexander et al. (1977), Harrison and Dourish (1996) define a distinction between space and place, and illustrate the influence of peoples sense of place on their interactive behavior. Designing information technologies for the domestic environment, Crabtree and Hemmings (2001) use an adapted pattern framework to inform requirements analysis and describe day to day use of technologies within that environment. Informing novel design of pervasive and mobile device services, Paulos and Goodman (2004) enquire into the application of new technologies by city inhabitants, and draw an analogy between Alexander's patterns and the movement and activities of people in urban settings. In line with this research, McCullough (2001) points out, that as interest in information technologies for physical contexts increases, what we already know from the work of people such as Alexander about the built environment and how people operate in it, can inform our understanding of peoples situated interactions, and guide the design of technologies that consider the user's physical context.

3. FIELD STUDY: FEDERATION SQUARE

Inspired by Lynch (1960) and Alexander et al. (1977), we conducted a field study of the architecturally designed built environment at Federation Square, Melbourne, Australia.

Figure 1. Federation Square.

Federation Square (figure 1) is a new civic structure, opened to the public in October 2002, to provide the people of Melbourne with a 'unifying square, a landmark, a civic focus' (official brochure), by bringing together a creative mix of attractions and public

spaces. The design intention for the space was to incorporate digital technologies into the building fabric creating a meeting of virtual information space and physical building space for people to experience. We chose Federation Square for this study because it is a multi-modal public space with a mixture of distinct architectural features and embedded digital elements that provide a variety of activities to visitors.

The aim of the field study was to inquire into how informational and architectural elements of the built environment contribute to the visitor's experience of a public place and how this could subsequently be modelled. Thus, we wanted to identify important properties of the built environment as an inhabited public space and create an analytical abstraction, which could inform the design of a mobile guide supporting visitors to this place. The result of the field study is a descriptive framework called MIRANDA (Multilayer Info Related to Arch aNalysis Data Abstraction), representing the human experience of the informational (analogue and digital signage) and architectural properties of a physical space. The result of the subsequent prototype design is a proof of concept for a mobile guide, which takes these properties into consideration.

- The study consisted of the following sequential activities:
- Field inspection of Federation Square
- Data coding (based on Lynch and Alexander)
- Data analysis
- Data synthesizing: developing MIRANDA
- Development of mobile guide prototype design

The field inspection took approximately three hours, data coding took eight hours, and data analysis took approximately three days. Synthesizing the data took eight hours and developing the preliminary prototype design took approximately two days. Although these estimates can serve as guidelines for similar analysis by other mobile guide designers, the exact time spent on these activities would depend on the size of the physical site being analyzed. The details of these activities are described below.

3.1. Inspecting Federation Square

An initial visit was made to Federation Square by the first author, and resulted in the development of a scenario of the experience of a first-time visitor to the square. Observational expert audits were then made of Federation Square for both architectural and information space, in two separate field visits. These expert audits were inspired by the method outlined by Lynch (1960) in his visual analysis of city precincts for the purpose of identifying types of elements of a city. In his method, an architecturally trained observer maps the presence of various elements of the physical environment. In this adapted method the trained observer records, through photographs and field notes, the elements of the physical environment for later classification using significant categories. These visits, taking about three hours each to complete, resulted in a collection of 250 digital photographs of physical elements of the built environment. The location of each photograph was recorded on a map of Federation Square, and corresponding observations of the relationship between the elements being photographed and the environment were recorded in the form of field notes.

3.2. Coding the data

The photographs were stored electronically in a format where they could be directly associated with their corresponding observational field notes and sketches, and could be annotated further during the process of coding and analysis. For the information elements, each sign and media screen was sketched showing its relationship to building fabric, viewing direction and distance, and then annotated with general field notes explaining the sketches and detailing auditor observations of human activity in relationship to the signage. For the architectural elements, field notes recorded observations made by the trained auditor including general descriptions of elements and human responses to physical spaces within the architecturally designed environment. The coding of this data was necessarily a two-phase process, given that the original source data was a mixture of images and descriptive text. The first pass through the data used the encoding schemas to convert classified elements of the images into corresponding text. The second pass combined the classification-generated image descriptions with existing observational field data and highlighted those aspects of the resulting prose that contributed to the encoded abstraction of that data.

In coding the information elements, the graphic communication theories and concepts of Bowman (1968), Tufte (1990) and Bertin (2003) were used to derive the following set of classifications for the information elements: type, direction, distance, visibility, readability, and location. These categories were used as an encoding schema, to group and order descriptions of sketches and field notes in the electronic file. The ordered descriptions were then read through in their entirety several times, and repeating phrases and key concepts associated with the encoding schema were highlighted in the descriptions associated with the images. Bowman (1968), Bertin (1983) and Tufte (1990) were used to develop the categories for the analysis of information space because their graphic communication theories are based on human interpretation and human understanding of graphic elements in signage, and therefore necessarily incorporate human experience of information into the analysis.

The architectural elements were classified initially using Lynch's (1960) categories of: district, landmark, node, path, and edge, as an encoding schema. Using Lynch's detailed descriptions of what constitutes each of these categories, the key element of each image was classified in respect to the schema, by the architecturally trained auditor using a visual inspection technique. The photographs were annotated with a legend indicating their association with one or many of the five categories. An additional classification of this data was then conducted on the architectural elements using the 253 patterns of Alexander's pattern language as an encoding schema. Sketches and notes showing the applicability of each pattern were appended to the existing field notes. Each image was associated with one or many Alexandrian patterns, and the photograph annotated with the pattern number and pattern title of each associated pattern. The text descriptions associated with each architectural photograph were then read through several times to identify key concepts and repeating phrases in the loosely structured data that related to the encoding schema. Lynch and Alexander were used to derive the encoding schemas for this analysis because the categories that they provide were the outcomes of empirical

studies of the interplay between architectural space and people, and this study aims to understand and model the human experience of a place.

3.3. Analyzing the data

Using a form of content analysis, adopted from rapid ethnographic method (Millen 2000), the highlighted concepts and themes were extracted from the descriptive prose, and analysed to see if some kind of 'vocabulary' of the space would emerge.

The architectural data was analysed first. The Lynchian categories derived from the image data were directly mapped and overlaid onto an existing two-dimensional map of Federation Square to produce a colour-coded abstraction indicating the location of the environmental categories. From this diagram it was clear that four key districts and four key landmarks could be identified in the complex. District 1 is a transit zone, a connector to the city, and has a focus on Landmark 1, the information centre. District 2 is the main plaza, an earthy uneven textured sloping open space with outdoors activities, which focuses on Landmark 2, the stage and large media screen. District 3 is the atrium precinct, sheltered, noisy, and constructed of machine-made materials, its focus is Landmark 3, the entrance, a large opening to this area. District 4 is the river precinct, which has the feeling of being at the back, flat, damp and lower than the rest of the spaces, Landmark 4, the river, is the focus of this district (see figure 2).

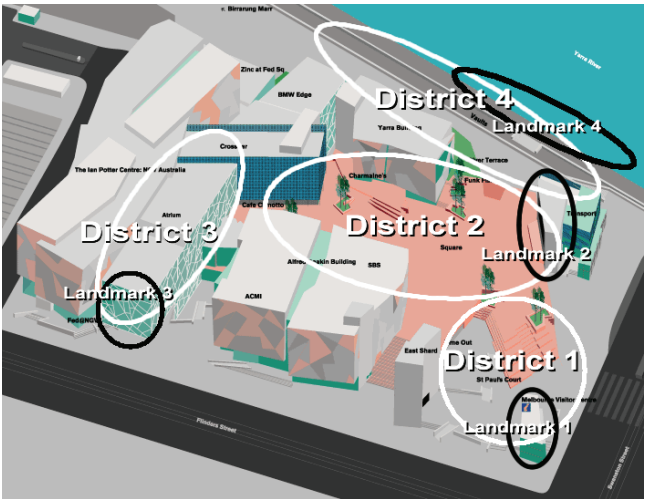

Figure 2. Federation Square: District and Landmarks.

The next stage was to use affinity diagramming adapted from the contextual design methodology (Beyer and Holtzblatt 1998) to group and refine the repeating phrases and key concepts that were identified in the data through the encoding process. Each phrase and word was written on a post-it note, and these notes were stuck on a large white board. After several iterations of grouping, regrouping, forming sets of words and refining words to a concise set of representative terms, the following themes emerged: words that described the space in terms of how it felt to people (affect), words that gave rich descriptions of architectural features, words that described the location of elements in relation to each other, and words that described human activity in the space. The

emerging words were, by virtue of the encoding schema, influenced by the categories of Lynch (1960) and Alexander et al. (1977).

The same process of affinity diagramming was used with the informational data, and the following themes emerged: words that related to the readability of signs, words that related to the visibility of signs, words that related to the physical location of the sign, words that described how people were using the signs, and words that described the quality and usefulness of information given (including the understandability and effectiveness of the information). The emerging words were, by virtue of the encoding schema, influenced by the classifications and descriptions of graphic communication used by Bowman (1968), Bertin (1983) and Tufte (1990).

3.4. Synthesizing the data: MIRANDA

The process of grouping, sorting, dissecting and refining word sets using the affinity diagramming method had resulted in an emergent 'vocabulary', for both the architectural and the informational data, which described the physical environment using a concise set of words and clarified and identified the essence of the characteristics of the space. The process had been iterated until the syntax of a 'language' and a stable and concise set of words, representing the semantics of that language, evolved. This language was necessarily refined to a point where it could be used to completely replace the text descriptions associated with each of the images, and hence be used to represent a concise and abstracted description of that space, providing a minimalistic representation of human understanding of that space.

The syntax of the language, MIRANDA, became a signed word-pair:

[+ , / , -]<descriptor>.<place>

Explaining this syntax, the first set indicates that only one of these signs, '+', '/', or '-', applies to the phrase, where '+' indicates the positive form of the phrase, '/' indicates the in-part form of the phrase and '-' indicates the negative form of the phrase. The sign is then followed by a word-pair, the 'descriptor' and 'place' words, each chosen from a finite set of describing words, and a finite set of place words, which were defined during the context analysis phase of the space. Together, they give the adjective and noun for a 'language' statement that can represent the human understanding of the environmental element being described. For example, '+ inviting.path' indicates that an inviting path is pictured, whereas '- inviting.path' indicates that the path is uninviting to people. The two sets of words that represent the architectural characteristics of Federation Square, in respect to the expert audit can be seen in figure 3 and 4, where descriptor words are on the left-hand side, and place words on the right-hand side.

The same synthesis process was completed for the information elements. The syntax of the information language that was emerged was:

[+ , / , -]<descriptor>.<attribute>

To confirm the richness of MIRANDA, one or many language statements were then used to replace the detailed prose description associated with each photograph to ensure that the key element of every image could be comprehensively described using the language. For example, the description associated with figure 1 was replaced by the language statements: '- clear.path', '+ activity.floor', and '- activity.middle'. These collected statements can be interpreted to indicate that the paths in this area are undefined, the paving on the ground and the steps in this area are primarily used as places to sit and watch, and the middle of the space is clear of activity. In the interest of a concise descriptor set, the word 'activity' was a composite descriptor that emerged from the grouping process, representing the following different types of activities that were extracted from the image descriptions: walking, sitting, strolling, meeting, watching, being seen, shopping, and dining. Future iterations of the language may have to include these more detailed activity descriptions, depending on the granularity of its use. To confirm the succinctness of MIRANDA, word pairs were associated diagrammatically using the abstraction shown in figure 3 and 4 to visualize variations and frequencies of word pairs.

This was done using layered drawing software, with each different coloured layer representing the links from a signed place word, to its associated set of descriptors. This made it possible to view different combinations of word pairs for comparisons with each other, and to make it possible to view all pairs simultaneously. Each occurrence of a word pair within the dataset was plotted on the diagram as an additional one-point line width to the connecting link between the words. When all the language statements had been plotted on the diagram, the width of the word pair link therefore represented the number of occurrences of this word pair in the total dataset. This gave a visual form to the 'language' and helped to validate the choice of words in the finite word sets by indicating whether word-pairs were actually used in describing the space, the existence of a link, and frequency of use of those pairs, the width of the link.

This abstraction of architectural characteristics provided an additional benefit as a tool for visualising a summary of human experience of architectural elements of that environment, that is, an overview of the physical context of that space. Surveying the diagram, it is possible to draw summary conclusions about the space which would not be evident from viewing the original data, or from merely visiting the space, because it represents a composite view of that space, judiciously extracted from historical understanding of human experience of architectural space, as a lens for expert observation and analysis of this built environment.

MIRANDA was also applied to the information layer of Federation Square (analogue and digital signage) but for the purpose of clarity and exemplification of indexing to physical context in mobile guide interface design, the remainder of the paper will focus on the outcomes of the architectural analysis as illustrated in figure 3 and 4.

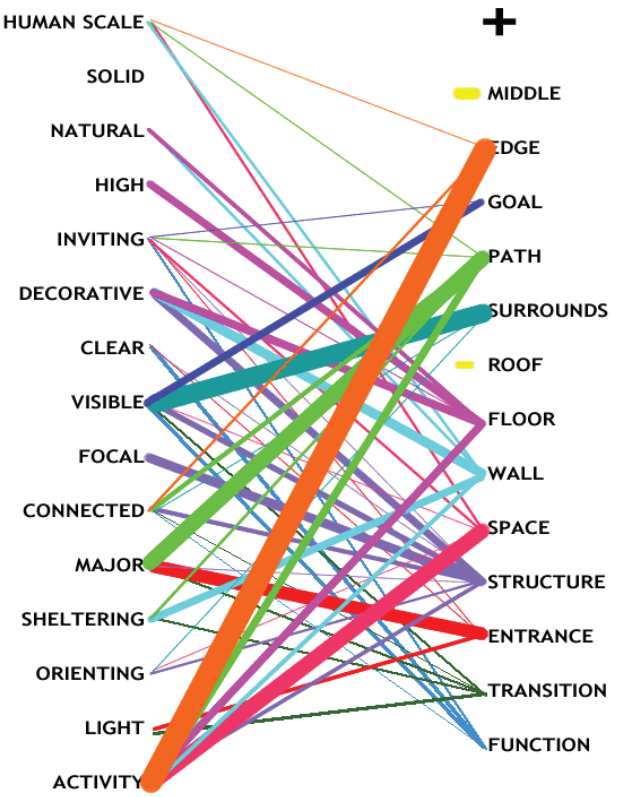

Figure 3. Abstraction of MIRANDA: positive description of architectural characteristics.

In analyzing figure 3 it is evident that activity in Federation Square occurs primarily along the edges and spaces generally have little activity in the middle. This can be surmised because the link between 'activity' and 'edge' is thick (+ activity.edge). We can also infer that the square looks out at the views of its surroundings, evidenced by the thick link between 'visible' and 'surrounds' (+ visible.surrounds). Many of the spaces have activities associated with them, such as places that are designed specifically for an activity such as sitting or dining, and so the link between 'activity' and 'space' is moderately thick (+ activity.space). Similarly, landmarks can be used to orient oneself, from most places around the square, indicated by the thick link between 'focal' and 'structure' (+ focal. structure). Other moderately thick links can be seen between 'major' and 'entrance' (+ major.entrance) and 'major' and 'path' (+ major.path), indicating that Federation Square has a few main entrances into buildings and main pathways around these structures, as opposed to a network of small pathways and multiple openings you might find in the centre of an old city.

Additionally, figure 4 enhances our understanding of the space by representing additional summary information about it in the form of the negation of these word-pairs. For instance, those major paths, that is, pedestrian links between two key destinations

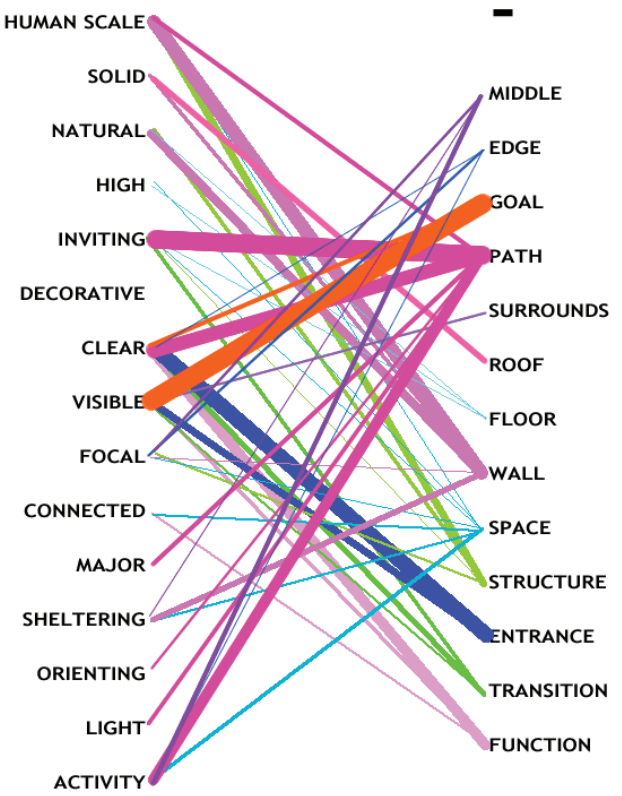

Figure 4. Abstraction of MIRANDA: negative description of architectural characteristics.

in Federation Square, are not inviting (- inviting.path). They are often either a narrow gap between two tall walls of adjacent buildings (- humanscale.wall) or they are down badly lit dark underground corridors (- light.path). When you are trying to find a specific place within the complex it is often difficult to see your destination, in several places you begin to follow a sign to a specific place, but the place that you are aiming for is not visible through the entrance indicated, leaving visitors unsure that it is the way to go (- visible.goal). In many places the pathway that you are supposed to take is unclear (- clear.path) because paths are not specifically indicated in open spaces.

This visual abstraction of MIRANDA represents a descriptive framework for understanding and modelling the physical context of a public place. MIRANDA makes available a vocabulary of a specific space that can then be used to understand the key physical characteristics of that built environment, and to describe the user's surroundings in a way that is grounded in human observation of that place, and formed with reference to collected knowledge about human understanding of architectural form and graphical communication. MIRANDA is unique, in so far as it is a systematic tool for creating an abstract representation of physical context, which does not exist in the literature surveyed, and yet that same literature often laments a lack of in-depth understanding

of the physical context for which pervasive information systems are being designed. The aim of creating MIRANDA is to provide mobile system designers with knowledge about elements in the user's physical context, so that information that already exists in the world can be indexed to in the interface. The use of MIRANDA for this purpose is exemplified below.

4. MOBILE GUIDE DESIGN

To explore the contribution of MIRANDA to the design of physically indexed interfaces, we have designed a mobile guide system for use at Federation Square as a proof of concept. The design presented below is currently being implemented as a functional prototype running on handheld computers using Bluetooth for positioning within districts and GPRS for wireless access to the Internet. The prototype will be lab and field-tested early 2005.

The design of the prototype guide system is based on a combination of the findings from the Lynchian analysis of Federation Square and MIRANDA. The Lynchian analysis showed that clear districts can be identified within the space of Federation Square. MIRANDA showed for each of these districts, key architectural characteristics can be identified on a level of abstraction that allows a conceptual image of the space rather than a catalogue of specific physical elements.

Combining the findings from the Lynchian analysis and MIRANDA, we have developed three overall design ideas for a mobile guide for Federation Square, which exploits unique characteristics of the physical space and indexes to features of the built environment:

- The mobile guide responds to the user's location in terms of one of the defined districts rather than Cartesian coordinate
- Each district is represented in the mobile guide by an interactive photorealistic depiction of the physical surroundings augmented with textual or symbolic information needed to better understand the plac
- Locations and instructions for navigation are expressed through rich descriptions derived from the distinctive characteristics of the place rather than through Euclidian coordinates

The implementation of three design ideas in our mobile guide system is detailed below.

4.1. Location by district

In our mobile guide for Federation Square, the user's location is defined by four districts. These four districts were identified by the Lynchian analysis, each with their own distinct characteristics and a corresponding landmark. The location districts we are using make use of people's ability to make sense of the physical environment in which they are situated and are not defined by coordinates but by the human experience of the physical layout of the space. Basing positioning on location within a limited number of districts rather than on exact x, y coordinates also makes it possible to implement positioning using, for example, Bluetooth beacons rather than GPS. The location districts of the mobile guide and corresponding screens are illustrated in figure 5.

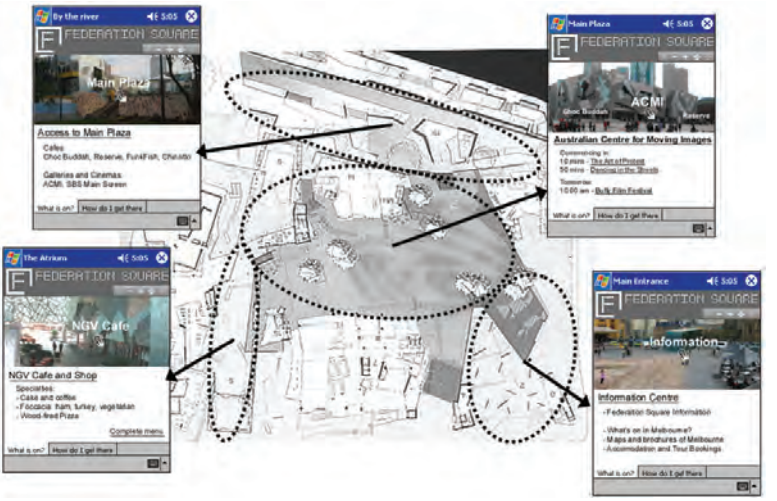

Figure 5. Location districts of the mobile guide for Federation Square and corresponding screens.

The information pushed to the mobile guide is tailored to information needs within a specific district. When a user moves into another district, their context changes, and so does the information that appears on the screen of their mobile device. To allow the user to align the information in the guide to their physical surroundings, the initial screen displays the corresponding landmark for that district.

In the following subsections, we describe the specific design of the screens associated with only one district, the main plaza.

4.2. Augmented interactive photorealistic depictions

When the user enters a district, an interactive photorealistic depiction augmented with textual and symbolic information pertinent to that district is pushed to their device. For the main plaza, MIRANDA identified six central architectural characteristics:

- Activity edges
- Focal structures
- No visible goals
- Visible surrounds
- Major entrances and paths
- No clear paths

These six features informed the interface design of the screens for the main plaza.

Wanting to represent the main plaza district in the system, we chose to use a 360° panoramic depiction of the plaza because MIRANDA tells us that the main plaza has 'activity edges' and is open in the middle. Focusing on the edges of the plaza will match the guide to the user's experience of the physical space and allow them to easily align the information presented in the system with their physical surroundings. We use photorealistic depictions in the design because we also know from MIRANDA that the main plaza has 'focal structures'. This enables users to align the image in the interface to

the architectural features of the built environment in their current district (for example, as seen in Pospischil et al. 2002). Subsequently, they can easily scan through the virtual representation of the space and index the information presented in the mobile guide to the corresponding physical objects in their surroundings. Like when operating a QuickTime VR movie, panning is done by pointing on the panoramic depiction and dragging in the desired direction.

In a situation where the physical analysis of a district indicated that features of interest were, for example, clustered or spread out over a very large physical area, it might be more appropriate to use a different depiction such as a bird's eye view approaching the user's perception of that space (see e.g. Kulju and Kaasinen 2002, Laakso et al 2003).

The main screen for the main plaza is shown in figure 6.

Figure 6. Mobile Guide for Federation Square: Location and Event finding screen.

MIRANDA also identified a characteristic of the space as having 'no visible goals'. This feature of the space led to the augmentation of the 360° panoramic depiction of the plaza with white text labelling visitor destinations not clearly indicated by the architectural design. In many cases the actual location of activities lies behind the visible facades, but the facades function as clear 'focal structures' that can be indexed to in the system, linking information provided by the system to those visitor destinations. A location is automatically selected when it is positioned in the centre of the display. This is indicated by the enlargement of the text label of that location and by displaying the associated detailed information, as shown in figure 6. From this screen, the user can access additional details by clicking on the underlined links. Access to navigation information about that location is also now available by clicking on the "How do I get there" tab.

4.3. Rich descriptions for navigation

When the user clicks on the 'How do I get there?' tab from the main screen, they are presented with location and navigation information about the selected destination. The design of the navigation screen, as shown in figure 7, was informed by MIRANDA identifying the architectural characteristics of 'activity edges', 'visible surrounds', 'major entrances and paths' and 'no clear paths'. On the navigation screen, the user is presented with rich descriptions derived from the distinctive characteristics of the place. The

descriptions used in the guide have two parts. The first describes the location in relation to focal structures. The second part describes the steps taken to get there.

Based on the knowledge from MIRANDA that activities are located on the edges, it follows that we are able to describe selected locations as being 'next to' and/or 'opposite' other locations on the edge of the main plaza. We use these terms in our rich descriptions, thereby indexing locations relative to one another. This is an alternative to absolute location descriptions typically used in mobile guides, for example 'located at the corner of Flinders and Swanston Streets', but holds more meaning to the users of the system, because it makes use of their understanding of the built environment.

Figure 7. Mobile Guide for Federation Square: Navigation Screen with rich descriptions.

The second part of the navigation information describes the path which the user should take to get there. We know from MIRANDA that paths in the main plaza are not clearly marked but that the urban surroundings are visible. This allows us to use descriptions, such as 'away from the train station' or 'towards the river', indexing to visible elements of the surrounding city. MIRANDA also tells us that access to the different locations surrounding the main plaza is afforded by major entrances. Based on this, the navigation screen contains an image of the entrance that the user must pass through to get there. Again, this indexes the information given by the mobile guide to the user's physical environment. Since some of the characteristics of a physical space sometimes may change in accordance to the time of day, season, special events etc. the rich descriptions in the system should be designed so that they can adapt accordingly.

5. CONCLUSIONS

As digital information becomes a part of the way we operate in the physical world, human computer interaction with mobile guides can benefit from making use of 'knowledge-in-the-world' by indexing to implicit information cues in the built environment. People have a strong ability to make sense of the physical space in which they are situated and often make use of this when using mobile guides in urban spaces. In order to exploit this ability in mobile guide design, we need to better understand the role of the user's physical environment in defining their context and the contribution of existing

information embedded in that environment to people's experience of it. Also, we need to make clear connections between the user's physical surroundings and the information presented on their mobile guide.

This paper has presented the outcome of a field study into the properties of a built environment that contribute to people's experience of their physical context. Synthesizing the outcome of the field study, we have proposed a descriptive framework, MIRANDA, which provides a summarized abstraction of the fundamental architectural and informational features of a built environment. The usefulness of MIRANDA in interface design has been exemplified through the design of an indexical mobile guide system for Federation Square, Melbourne, Australia. Unlike other location-aware guide systems, the proposed design explicitly uses insight into user perceptions of architectural characteristics of the built environment to tailor the information presented to the physical context, in which it is being used.

While the outcomes of our analysis are specific to Federation Square, the empirical analysis of an environment used to create the MIRANDA framework could be applied to other cases of mobile guide design for the built environment. In physical spaces where a MIRANDA-based analysis reveals similar architectural characteristics to Federation Square, the specific design ideas of exploring indexicality presented above could also be applied.

The proposed design sketches are currently being implemented as a functional prototype. Through laboratory- and field-based evaluations at Federation Square, the prototype will allow us to validate the usefulness of MIRANDA for informing the design of mobile guides for use in built environments.

In future research, the proposed descriptive framework of MIRANDA should be refined and validated through further studies of other built environments both similar to and different from Federation Square. Additionally, it would be interesting to investigate further the dynamic aspects of physical spaces; characteristics changing according to time of day, season, special events etc. The proposed method does not take this issue explicitly into account during the data collection phase and would have to be extended for this purpose.

ACKNOWLEDGEMENTS

The authors thank Steve Howard and Bharat Dave for valuable supervision on the project and comments on the paper. The field study was designed and conducted by the first author, who was also responsible for the data analysis and development of MIRANDA. The design of the mobile guide for Federation Square was done in collaboration with the second author as a part of the "Design and Use of Context-Aware Mobile Multimedia Systems" and "Indexical Interaction Design for Context-Aware Mobile Computer Systems" research projects supported by the Danish Technical Research Council (project references 26-03-0341 and 26-04-006).

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Chapter 4

Social context

Jeni Paay and Jesper Kjeldskov

Abstract. Ubiquitous and mobile computer technologies are increasingly being appropriated to facilitate people's social life outside the work domain. Designing such social and collaborative technologies requires an understanding of peoples' physical and social context, and the interplay between these and their situated interactions. In response, this paper addresses the challenge of informing design of mobile services for fostering social connections by using the concept of place for studying and understanding peoples' social activities in a public built environment. We present a case study of social experience of a physical place providing an understanding of peoples' situated social interactions in public places of the city derived through a grounded analysis of small groups of friends socialising out on the town. Informed by this, we describe the design and evaluation of a mobile prototype system facilitating sociality in the city by 1) allowing people to share places, 2) indexing to places, and 3) augmenting places

1. INTRODUCTION

Mobile and ubiquitous computer technologies are increasingly being appropriated to facilitate people's social life outside the work domain linking people to people to places (Jones et al. 2004). Mobile phones, and especially SMS texting, have changed the way people communicate, interact in the physical world, and coordinate their social activities (Grinter and Eldridge 2001; Rheingold 2003). By embedding networked sensors into the built environment, adding advanced positioning technology and short range network capabilities (such as Bluetooth, RFID tags, etc.), context-aware mobile services are emerging that adapt their content to both the user's physical and social context.

When designing mobile services for fostering social connections and augmenting our physical built environment, system developers and interaction designers are faced with a series of new challenges. We need to understand better the physical and social context of the user's situated social interactions (McCullough 2004), the role of human

Originally published as Paay, J. and Kjeldskov, J. (2008) Situated Social Interactions: a Case Study of Public Places in the City. *Computer-Supported Cooperative Work,* 17(2-3), 275-290.

activity within the built environment (Ciolfi 2004) and the interplay between context and user actions (Dourish 2004). We also need to understand how physical and social affordances of a place influence the situated interactions that occur there, including the relationship between people, technology and interactions. Finally, we need to define useful and understandable ways of incorporating peoples' physical and social context in interaction design for context-aware mobile services.

Recent work in human-computer interaction (HCI), computer-supported cooperative work (CSCW) and interaction design has examined how the concept of *place* can contribute to our understanding of peoples' interactions within their physical environments and with ubiquitous computing technologies augmenting this environment, and how the notion of place can inform system and interaction design.

This paper addresses the challenge of informing ubiquitous and mobile technology design by using the concept of place as a central notion for studying and understanding peoples' social activities in a public built environment. We present a case study of social experience of a physical place providing an understanding of peoples' situated social interactions in public places of the city derived from a grounded analysis of small groups of friends socialising out on the town. Informed by this, we describe the design and evaluation of a context-aware prototype system facilitating sociality in the city by 1) allowing people to *share places,* 2) *indexing to places,* and 3) *augmenting places.*

The paper is structured in the following way. Section 2 discusses related work focusing on people, technology and interactions in place. It presents and discusses our understanding of place, ubiquitous technology use in city contexts, and introduces the concept and typology of situated interactions. In section 3 we present our field study of people socialising in public places, describing the details of our empirical method and data analysis. In section 4 we present the findings from our study of situated social interactions in public places. To illustrate the value of understanding social interactions in place for informing interaction design of mobile services, section 5 describes the design and evaluation of an implemented prototype system, which adapts to the user's physical and social context to foster social connections in that place. Section 6 concludes on our study.

2. BACKGROUND

2.1. People in place

The design of the city affects how people make sense of the social complexities of urban places. The architectural design of form in the built environment has traditionally occurred within the context of an explicit set of social and physical issues in respect of anticipated activities and historical expectations tied to particular institutions and building types (Agre 2001; Mitchell 1995). Physical and social affordances of a place have helped to define the social interactions that occur there (Gaver 1996). Physical space plays a constructive as well as a receptive role in shaping social interaction in urban places (Hillier and Netto 2002). Space is given significance and becomes place through its link to human activity. We are located in space, but we act in place. Our shared understanding of the physical world helps people in presenting and interpreting

activity and behaviour (Harrison and Dourish 1996). The physical and social layers of a space form the context of interaction for its inhabitants, intimately connected to their activities (Donath 1996). Accumulated experience helps people to identify with a place and in turn gain an understanding of what is going on in that place. Understanding the context of social interactions is an important part of designing ubiquitous computing that delivers information to people in the places and activities of their daily life (Agre 2001).

2.2. Technology in place

Architectural ideas about the nature of place are being challenged as communication and computation devices begin to saturate the built environment (Rheingold 2003). Ubiquitous computing is breaking down the traditional mapping between activities and place, allowing people to participate in social interactions that are no longer tied to their current location by supporting continual presence in every place (Agre 2001). For example, cafés become corporate meeting rooms as users deal with business calls over lunch, without any changes to the physical fabric of a place. Technology is uncoupling the close relationship between activities and place previously imposed by architectural design allowing social interactions to extend beyond a person's current physical location. Places no longer define appropriate activities by their physical design alone: now every place can be for everything, all of the time (Agre 2001; Mitchell 2003).

Understanding how to design ubiquitous computing that meshes with human behaviour and the properties of place that structure human interaction is immensely important (Ciolfi 2004; Erickson 1993). People who are digitally connected to each other and to the elements of the city use that technology to deliver information that is "just in time" and "just in place", to guide them to where they want to go and inform them about possible activities. This digital layer not only helps to structure our social interactions, but also provides a social medium for facilitating and enriching every day interactions between individuals (Erickson 1993).

Mobile services are increasingly becoming a part of the way we operate in urban places. Context-aware mobile information systems provide access to contextually adapted information and can foster social connections by sensing and responding to groups of co-located people in a place. In essence, they are connected to and respond to the place in which they are operating. The design of context-aware mobile information systems covers a broad spectrum of application areas, many of these mobile information systems involve the user being situated in urban public places, and yet only a few have investigated the challenges imposed and the opportunities offered through a grounded understanding of the relationship between activity and place.

2.3. Interactions in place

Studying people's "everyday action" can provide designers with a sense of the meaning associated with user activities, knowledge about what they actually do in a particular situation, and an understanding of people's experience of place. As Ciolfi (2004, p. 39) says, "understanding the dynamics of interaction in a space can help us design more effective systems in responding to behaviour and to changes in the environment."

McCullough (2004) approaches this problem with the idea of using typology (the study of recurrent forms) as a design philosophy to provide types of everyday situations as a way of abstracting an understanding of the influence of place on interaction. Using typology as a design philosophy provides a framework for creativity, allowing design to be based on themes rather than arbitrary innovation. It acknowledges existing living patterns of an inhabited place and helps designers of digital technology to recognise situated interactions and make technology a simpler, more adaptive and more social part of those interactions. McCullough asserts that place becomes reconfigured by ubiquitous computing not replaced by it, and that technology then extends the living patterns of that place. This approach to information technology design focuses on the need to understand how people interact in place. Gaining that understanding can be used to facilitate human-centred design of mobile services for fostering social connections.

A rudimentary typology of 30 everyday situations that may be transformed by technologies is proposed by McCullough (2004). This typology classifies situational types, grouped to reflect the following categories of place: workplace, dwelling place, the "third place" for conviviality, and the "fourth place" of commuting and travel. By using this typology as an analytical lens in this study, the concept of place becomes an organising theme for the data collected. This also limits the focus of the fieldwork to a manageable range of recognisable situations, allowing for design variations to benefit from being based on a few appropriate themes (McCullough 2004). As derived from McCullough (2004), the situated interactions associated with places for conviviality, that is, being out "on the town" are: places for socializing, places to meet, places for seeing and being seen, places for insiders, places for recreational retailing, places for embodied play, places for cultural productions, and places for ritual.

3. FIELD STUDY: PEOPLE SOCIALISING IN A PUBLIC PLACE

Exploring the interplay between people, activity and place, we conducted an empirical field study of situated social interactions in the city. This study investigated the use of McCullough's (2004) typology of "on the town" everyday situations to guide fieldwork for informing interaction design of a mobile information system for a public place. The field study took place at Federation Square, Melbourne, Australia (figure 1). Federation Square is a new civic structure covering an entire city block, providing the people of Melbourne with places for a variety of activities including restaurants, cafés, bars, a museum, galleries, cinemas, retail shops and several public forums.

Figure 1. Federation Square, Melbourne, Australia, with surrounding skyline and river

3.1. Participants, procedure and data collection

The field study was conducted on location at Federation Square using the rapid ethnography method (Millen 2000). McCullough's (2004) typology focused the research scope at the beginning of the fieldwork by suggesting places for observations, and contextual interviews (Beyer and Holtzblatt 1998) facilitated interactive observation. Three different established social groups participated in the study as key informants. Each group consisted of three young urban people, mixed gender, between the ages of 20 and 35, who had a shared history of socialising at Federation Square. Each group met at Federation Square where they were not given any specific tasks but were asked to simply undertake the same activities that they would usually do as a group when socialising in the city. Each contextual interview and observation lasted approximately three hours (figure 2). Digital video was used to document all questions, responses, activities and movement of the group around the square.

Figure 2. Contextual Interview

Figure 3. Affinity Diagramming

3.2. Transcriptions and data analysis

Shortly after the field visits all recordings were reviewed and situated interactions transcribed. The analysis of the transcript involved open and axial coding adapted from the grounded theory method (Strauss and Corbin 1990) chosen for its structured bottom up approach to analysing data to generate themes, and affinity diagramming (Beyer and Holtzblatt 1998) as a method for hierarchical grouping of themes (figure 3). Grounded theory analysis produced 107 novel themes describing interactions and their relationship to place and activity. The affinity diagram refined these to a small set of high-level concepts, representing the essence of the data and encompassing all lower level themes, structured in a conceptual framework around the three key concepts of *knowledge, situation,* and *motivation* as described in section 4. Orthogonal to these concepts, three "place-related" design ideas of *sharing place, indexing to place,* and *augmenting place* were drawn, implemented and evaluated, as described in section 5.

4. SITUATED SOCIAL INTERACTIONS IN PUBLIC PLACES

The conceptual framework encapsulates a structured understanding of every day social interaction in the situation of a public place. It provides an understanding of the role of physical and social context in how people experience a physical place and how they interact with each other while socialising, in the form of a qualitative story woven around three key concepts: knowledge, situation and motivation.

4.1. Knowledge

Knowledge is an important part of how we operate while socialising in an urban environment. When interacting in urban places people use their understanding of the world around them to make sense of things.

In the study, participants operated using the physical affordances (Norman 1990) of elements, for example, assuming steps with high risers as being for sitting. They saw large open spaces as places for people to gather. If a space had a visual focal point then it was regarded as a good place for locating a special event or performance. Visible openings in facades indicated entrances, and architectural features such as low walls defined boundaries for sitting or walking and in this way confined activities. Participants drew on their history with that specific urban environment. Physical familiarity with a space meant that they approached familiar places using familiar paths, that is, the way that they "usually come". A familiar path was not perceived as the long way round, even if it was in terms of physical distance and they often assumed that others had the same familiar paths.

Participants also operated in public places using a set of social affordances. They looked to what other people were doing as cues for what to do in a place. Following crowds or people queuing was a way for them to decide where they might go. They looked at others to confirm what activities were acceptable in a place. Places where others were sitting made them feel they might sit there too. They read the presence of many people in an establishment as a recommendation that it was a good place to go. Participants expressed a desire to socialise where others were relaxing and enjoying themselves and were drawn into a place where they could see this happening from the outside. They also used social experience as a basis for selecting places to socialise with friends and their own past experience or shared group experience to index to past social events, for example "let's meet where we met last time". The impression of liking a place was based on successful past visits. Trying new places was based primarily on recommendations from friends or trusted media reviews. If they were socialising with a group of friends they met in the place where they usually met with those particular friends.

4.2. Situation

Situation is an important aspect of sociality in urban space. When socialising the presence of both friends and strangers influences the way that people behave and move through urban place.

In the study, friends maintained their sense of "group" by the way that they physically located themselves in a public place. As they moved through space they often walked abreast, or single file in crowded situations, but always very much together. When they stopped they gathered in a circle to discuss options and excluded the outside from the interaction.

Participants liked to be near others but not necessarily interacting directly with them. One participant called this "socialising by proximity" meaning that they wanted to be amongst others, often enjoying sharing a long table with several other groups in a place, but not feeling as if they had to talk directly to them. They liked to watch others, especially if they felt unobserved themselves. This generally meant being in an elevated

position compared to the people they were watching or behind a low wall or plant box, to keep others at a distance. They mostly engaged in this activity when on their own.

Participants liked to wait for others in a place where they could see their friends arriving, specifically in a location that overlooked the entrance to a place, for example, at a table facing the door of a bar. The length of time that they had to wait affected the choice of meeting place. If their friend was going to be a long time (defined by participants as 30 minutes or more) they wanted an activity to do while waiting. If it was a short time (a few minutes) convenience to the meeting place was more important. Sitting outside at bars and cafes was perceived as more comfortable than waiting alone inside.

Setting influenced sociality. The presence of others and the types of people in a place influenced its acceptability. Participants expressed that they liked to socialise in places with similar types of people, i.e., age, dress, intentions. Environmental comfort was also important. Whether a place was sunny, sheltered, etc., influenced the choice of location to socialise or wait. Participants preferred sitting outside socialising in nice weather. They also preferred to sit in an elevated position with an interesting view out. The convenience of a place was also important. Participants preferred starting a "night out" in a location that had other activities they might like to do nearby.

Surroundings were an important part of situation and were often used as reference points. Participants indexed to things around them and to experiences shared with the friends they were with. They gave directions to a friend by referring to shared places and activities such as "next to the place we went last time where we sat in the sun". Participants also referred to visible elements, pointing to them or referring to generally known events or physical objects, including landmarks. For example, they would often use statements such as "through that opening", or index to landmarks in their surroundings, such as "it's near the big screen". Connecting stairs or pathways between physically separated spaces formed major transition points used in descriptions on how to get from one place to another.

4.3. Motivation

Reflection on current experience is part of socialising in a place. People try to size up the situation and like to get an overview of what is happening in a place. Before entering a place they stand back and familiarize with it and often pause before committing to a situation.

In the field, participants strived to make sense of things and places around them. Even if they had already decided to go to a familiar place, they would stand outside and review the menu before going in. Making sense of how things were organised was based on people's past experience with similar situations and by assessing the activities of others. Participants made very little use of signage, information kiosks or media screens in trying to do this sense making. Media screens while ostensibly informative were often regarded as decoration, something to make an environment more exciting. If they had a query, they usually asked a friend.

Participants gathered information about a place while socialising in it. Individuals required different levels of information for different activities. Those who required the most cursory level of information often set the pace of the group, others requiring

more detail said they would only seek this depth of information when on their own. All participants wanted to know what was new in a place and if something special was happening.

In way finding, participants navigated by familiar paths and looked ahead for structures, objects and landmarks that they recognised and knew were near their destination. Participants discovered that urban spaces were dynamic, and paths were sometimes altered by the presence of crowds and temporary or new structures. In this situation, they avoided unfamiliar paths if they were not sure where they led, searching for the nearest familiar place and preferring to walk toward light rather than dark paths.

Extension of knowledge about a place often motivated social activity. Participants took part in exploration for the sake of it by wandering and browsing in a space. Sometimes they just wanted to know what was going on without any intention of joining activities. They enjoyed browsing as a group activity, allowing displays in shop windows to draw them in, and spent time negotiating what to do and where to go next.

5. DESIGNING FOR SITUATED SOCIAL INTERACTIONS

Inquiring into the usefulness of the understanding represented by the conceptual framework for informing interaction design, we designed, implemented and evaluated a prototype system for fostering social connections "in place". Firstly, we conducted a two-day design workshop to derive design ideas – or "design sensitivities" (Ciolfi and Bannon 2003) – for a context-aware mobile information system supporting sociality in the city. Following this, several iterations of paper-prototyping (Snyder 2003) turned the most promising ideas into a high-fidelity paper prototype. Subsequently, we implemented the paper prototype as a functional web application running in Microsoft Pocket Internet Explorer on HP iPAQ h5550 using mySQL, PHP, pushlets and server-side applications for handling context-awareness and dynamic generation of maps and graphics. The final system keeps track of the user's location, their current activity and friends within close proximity. It also keeps a history of the user's visits to places around the city. The technical details of the prototype are described in Kjeldskov and Paay (2005). The prototype system was evaluated by studying peoples' use of it for approximately 1 hour in either a laboratory or while socialising at Federation Square. The evaluation participants were 20 established social pairs familiar with Federation Square (10 in the lab and 10 in the field), and the prototype was pre-loaded with details about the participants' history of social interactions at Federation Square, together as well as on their own or with other people, derived from a pre-evaluation questionnaire.

In this section we focus on describing three of the seven design ideas emerging from the fieldwork to illustrate the resulting prototype design, and highlight feedback from the evaluations. Each design idea was drawn directly from themes and categories in the conceptual framework:

- Sharing place: recommendations based on history and context
- Indexing to place: way-finding referring to the familiar
- Augmenting place: representing people and activities in proximity

5.1. Sharing Place: Recommendations Based on History and Context

Evidenced in the data by the way people make decisions about where to go, was the importance of people's past experiences in terms of their existing knowledge, history of visits, social experience with places, and their current social group. This was explored using a sketch to examine the relationship of experience between two people, A and B (figure 4 left). Looking at the sketch from A's point of view, A has a past history which includes a number of familiar places. A subset of A's history is shared with B and represents shared experience which can be referred to through indexical relational descriptions such as "where we met last time". B also has a past history of familiar places that A has not been to. When A and B are socialising these places become recommendations from B for new places for A to go.

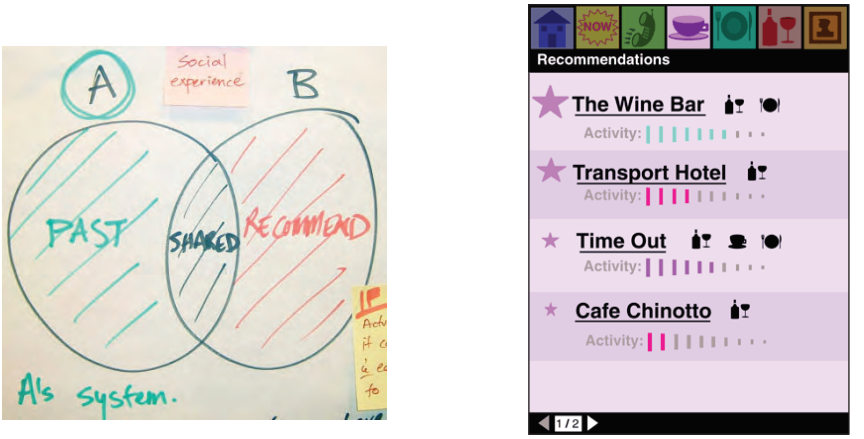

Figure 4. Design sketches: indexing to peoples' individual and shared histories

On the basis of the overall design idea of indexing content to the users' individual and shared histories, the prototype was designed to facilitate "sharing place" by ranking recommendations about places to go. When a member of a social group (the user) selects a specific activity on the device, for example, "having coffee", it presents a list of recommendations of places to go (figure 4 right), ranked on the basis of the systems knowledge about the user's familiar places (where the user has been to before together with these friends), current social setting (places that people in the current social group have been to before but not together), the current environmental setting (how well the weather situation of past visits to a place fits the current conditions), and convenience (places within the vicinity of the social group). Each place has an associated "activity-meter" displaying the current patronage and primary activity to accommodate the finding that setting matters in relation to the presence and similar intentions of others in a place. This gives the social group a chance to pause before committing to an activity or a place.

Studying the use of this feature in the evaluation of the system, we found that people generally thought it was interesting to be able to share information about places they liked to go to and also be able to explore new places in a space through implicit recommendations from the friends they were with. However, they also expressed that

they would like to have more control over the system's methods for ranking of places. On the interaction design level, we found that while people generally understood that the system adapted information to their location in space and to the places around them, they were surprised that the system also adapted to their social context (who they were with) and had to have this explained to them indicating that this design lacked the necessary interface cues for them to fully understand it.

5.2. Indexing to Place: Way Finding Referring to the Familiar

The data collected shows that people seldom navigate by means of detailed maps and route descriptions when making their way around a space such as Federation Square as a part of a social group out on the town. Instead they use their history and especially physical familiarity with a space or place as well as physical affordances, such as visible places to enter and landmarks, to find their way around a space. They rely on simple indexing to their familiar places and prefer to follow their familiar paths from one place to another even if this may not be the most direct route. This finding was used to develop a sketch of the idea of basing wayfinding instructions on simple, indexical references to landmarks and familiar places with consideration to the user's history of familiar paths rather than the most direct route (figure 5 left).

Figure 5. Design sketches: indexing way finding to familiar places and paths

In the prototype, the "Getting There" option displays information to the user about how to get to a destination from their current location based on references to places where they have been before, for example, "Chocolate Buddha is located next to ACMI Cinemas opposite Arintji" (figure 5 right). If the destination is not in the vicinity of anything known by the user, the way-finding descriptions direct the user to the familiar place or landmark closest to the destination and give detailed directions from there. The way finding directions are combined with photographs of places, landmarks and transition points providing information that takes into consideration what people already know about places around them, and acknowledges their ability to make sense of an unfamiliar place on the basis of a few simple cues to familiar elements.

Studying the use of this feature, we found that people were highly capable of making sense of sometimes very reduced and fragmented information when it related to places

they already knew. People were good at matching up objects, structures and outlines in their physical surroundings to images on the screen. Using pictures as reference points for both familiar places and for significant structures and elements of the surrounding space helped "fill in the gaps" in the way finding instructions.

5.3. Augmenting Place: indicating People and Activities in Proximity

Another important observation made from our field study was the importance of knowing about the existence of other people in a space and what they are doing. The interaction between a social group and the co-inhabitants of a space is complex. It involves a certain level of interaction between the group and others, either by proximity or by watching. Observing where other people are gathering and what they are doing there helps in getting an overview of a place, making sense of what is happening and sizing up the situation, which are an important part of pausing before committing to enter a place. This finding was used to sketch and develop the idea of representing current activities of others within close proximity (figure 6 left).

Figure 6. Design sketches: representing activities and people in proximity

In the prototype, when the user selects "NOW" in the main menu it displays a small map of the user's immediate surroundings (figure 6 right). On this map superimposed, dynamically updated coloured circles indicate the clustering and activities of people within proximity. The radius of the circles indicates the number of people at a place while the colour represents their primary current activity (e.g. purple shows people "having coffee"). The map also shows the location of the user. By clicking on the coloured circles the user can access more information about each place.

Studying the use of this feature, we found that people were fascinated with the idea of knowing about people, places, and activities in the space immediately surrounding them. This was perceived as being of great interest and value for getting an overview of a public place and for informing discussions among the group about what to do and where to go next. People happily made detailed assumptions about the presence and activities of other people in the places around them based on this relatively simple graphical representation.

6. CONCLUSIONS

We have presented a case study of human experience of a physical place providing an understanding of peoples' situated social interactions in public places of the city derived from a field study of small groups of friends socialising out on the town. Based on a grounded theory analysis of our findings we have presented a qualitative conceptual framework of situated social interactions in a public place, and illustrated how this conceptual framework informed the design of a mobile context-aware prototype for supporting sociality in the city. This was achieved by providing a place-based understanding of people's situated social interactions in an abstract form inspiring design rather than specifying system requirements. Finally, we have presented preliminary empirical findings about the interplay between technology, people and place.

The literature calls for extended understanding of the contexts of everyday activities (Agre 2001; Ciolfi 2004; Dourish 2001; Erickson 1993; McCullough 2004). This is especially important when designing ubiquitous and mobile computer systems pervading the places and social activities of daily life. We need to understand better the user's physical and social context, their situated social interactions (McCullough 2004), the role of human activity within the built environment (Ciolfi 2004) and the interplay between context and user actions (Dourish 2004).

Understanding how people behave in public places can be interpreted by considering their social and physical context, that is, the roles of others and their surrounding environment. The presence and activities of people in the built environment gives locations in space cultural and social meaning, transforming spaces into places. The history of interactions in a place, and the experience of similar situations in other places, all influence peoples' perception and understanding of a place. To be able to design mobile services for fostering social connections in place, their situated social interactions need to be understood in respect to the physical and social context in which they occur.

Applying the notion of place to the study of peoples' situated social interactions in the city provides a useful lens and conceptual foundation for generating such understanding about the interplay between people, activities and place, and for informing the design of new ubiquitous and mobile technologies "augmenting the city".

ACKNOWLEDGEMENTS

This research is supported by the Danish Technical Research Council (26-04-0026), the Smart Internet CRC, Australia, and The University of Melbourne's David Hay Award program. The authors thank everyone participating in the field study and prototype evaluations. We also thank Steve Howard and Bharat Dave for valuable inpu.

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Chapter 5

Personal context

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Abstract. Intimacy is a crucial element of domestic life that has received insufficient attention from Human-Computer Interaction (HCI) researchers despite their rapidly growing interest in the design of interactive technologies for domestic use. Intimate acts differ from other activities, and there are unexplored opportunities to develop interactive technologies to support these acts. This paper presents the first phase of a two-part study exploring the potential of interactive technologies to support intimate relationships. We contribute to this uncharted domain of HCI research a literature review of concepts useful in understanding intimacy and methods for its investigation. We conclude with preliminary results and suggestive design ideas for interactive technologies intended to support intimacy.

1. INTRODUCTION

Interest in the design of interactive technologies for domestic use has been growing within the Human-Computer Interaction field (Hindus 1999). Recent research has fruitfully examined the instrumental activities involved in coordinating and scheduling family behaviour (Harper 2003), produced rich studies of the multiple meaning attached to domestic routines (Crabtree 2003), performed empirical and technological explorations of fun and leisure (Blythe et al. 2003) and developed proposals for aids to help family members stay in touch (Hofmeer 1999). Inspired by this research, we have been investigating and exploring a crucial element of domestic life that has received relatively scant attention to date from HCI researchers – intimacy. Our research is motivated by a desire to understand how intimate relationships between close family members might be supported by interactive technologies with a view to designing domestic and personal technologies for this very purpose.

Originally published as Kjeldskov J., Gibbs M., Vetere F., Howard S., Pedell S., Mecoles K. and Bunyan M. (2004) Using Cultural Probes to Explore Mediated Intimacy. *Australasian Journal of Information Systems,* 11(2), 102-115.

Intimate relationships are different from the kinds of relationships that have been typically studied by HCI researchers such as those found in the workplace or amongst social networks of friends. Intimate acts also differ from the domestic behaviours usually addressed in the literature (see Harper 2003 for a review) and attempting to study acts of intimacy presents the researcher with a number of unique and interesting challenges. Studying intimacy is challenging because intimate acts are ephemeral and transient yet ubiquitous and crucial to the ongoing life of an intimate relationship. They form the material and background of close personal relationships, yet occur in the doing and then often vanish unremarked. While the informational content of intimate acts may be low and seemingly trivial to outsiders, the act itself can be laden with emotional significance for those involved. Intimate acts often entail self-disclosure, and thus privacy is a concern. Much of what passes between intimates is unsaid and premised on deep knowledge and understanding of one another and occurs in the context of a rich, shared and sometimes idiosyncratic view of the world that may be difficult for others to fathom and comprehend. Intimacy also involves assumptions about commitment and mutuality, and carries nuanced expectations for reciprocity and exchange that are negotiated and arrived at over many years, yet remain fragile and are occasionally misjudged leading to misunderstandings and conflict. Finally, unlike instrumental tasks (e.g. coordination of family activities), or leisure activities (e.g. games) there is no generally accepted language for describing and discussing intimacy, especially in relation to designing technologies for its support.

In this paper we present our response to the interesting issues and challenges arising from our efforts to understand how intimate relationships can be supported with interactive technologies. Our study of 'mediated intimacy' has been divided into two major phases. In the first phase, we have focused on understanding current practice. To this end, we have adopted the 'cultural probes' techniques developed by Gaver et al. (1999) and the Equator team (Cheverst et al. 2003) and extended them with contextual interviews (Beyer and Holtzblatt 1998). We have used these methods to investigate how people appropriate and use the gamut of artefacts, devices and interactive technologies at their disposal to perform the various communicative acts that enable and sustain their intimate relationships. While we have adopted methods that are gaining prominence in the HCI community for investigative work in the domestic environment, how best to explore and understand intimacy remains an open and unexplored question. As a result, the first phase of our study has also had a strong methodological flavour with the aim of developing and refining techniques suitable for investigating these, and similar, phenomenon. The second phase of our study will take the insights and understandings generated in phase one and use them to design interactive technologies to support intimacy. These insights will feed a range of design activities such as the development of use scenarios, participative design workshops, prototype development and evaluation. At the time of writing, the first phase of study has been largely completed and the second phase is about to begin.

In the following section of this paper we present the results of a wide-ranging cross-disciplinary review of the intimacy literature. This review has two parts, the first being a theoretical discussion of the prominent and common themes and concepts found

throughout the intimacy research literature. We also consider the use of artefacts to mediate intimacy, with a particular focus on interactive technologies. Mundane artefacts and existing interactive technologies are considered. In addition, a selection of recent prototypes and exploratory interactive technologies that attempt to mediate family relationships are reviewed. We describe in detail our research approach because of its potential for inspiring and informing (Crabtree et al. 2003) the design of interactive domestic technologies. We then present preliminary results from the first phase of our study of current practice, highlighting the key analytic themes that have emerged from our investigation of how interactive technologies are used within intimate relationships. Based on these finding, we offer three, broad-brush and indicative suggestions for the design of interactive technologies to support intimacy.

2. WHAT IS INTIMACY?

Although there are many interesting discussions and perspectives, there are no agreed-upon definitions of intimacy (Register and Henley 1992, Moss and Schwebel 1993, Robson and Robson 1998). In this section, we discuss what constitutes intimacy. We believe a clearer understanding of intimacy is important because it provides a basis for the design of artefacts that better support intimate relationships. With the purpose of understanding intimacy and its contributing factors, we conducted a literature review of conference papers, journal papers and book chapters. This section extracts some of the major themes from this review.

According to Cheal (1987), an intimate relationship consists of a private world of significant others, which needs to be continuously maintained. In intimate relationships the significant other is often reminded that "they are indeed significant". People remind each other through gestures, actions and gifts, some of which may be routine and unremarkable. Our study provides an opportunity to investigate these exchanges of intimacy. The literature provides a framework or 'lens' for conducting the observation.

While the literature provides no unanimous agreement about what constitutes intimacy, some common themes do appear. Our review offers eight prominent aspects of intimacy. These are: *physical intimacy, non-verbal communication, self-disclosure, presence, cognitive intimacy, affective intimacy, commitment* and *mutuality*.

Physical intimacy plays a central role in people's description of their own intimate behaviour (Robson and Robson 1998) and is acknowledged as an essential aspect of intimate relationships (Register and Henley 1992; Battarbee et al. 2002). Physical intimacy is the sharing of physical encounters ranging from close physical proximity to sexual contact (Moss and Schwebel 1993). Physical intimacy is not only concerned with bodily contact. Physical intimacy also includes the visceral experience of heightened awareness of ones own body or feelings of new bodily experiences (e.g. butterflies in the stomach, weak at the knees), arising from physical or mediated contact with another (Register and Henley 1992).

Non-verbal communication is identified by several researchers as a significant carrier of personal expression in intimate relationships. Non-verbal communication is communication by means of actions, gestures, facial mannerisms, close physical proximity

or touch (Register and Henley 1992, Battarbee et al. 2002). Non-verbal communication is the aspect of intimacy that is better expressed through sensory evocations rather than linguistic forms, and helps to avoid the confusion that is sometimes caused by words (Register and Henley 1992).

Self-disclosure is a key characteristic that often differentiates intimate from non-intimate relationships (Register and Henley 1992, Moss and Schwebel 1993, Robson and Robson 1998). Self-disclosure is the act of revealing private information, such as the personal feelings of one person toward another. Self-disclosure includes the removal of boundary between oneself and an intimate other (physically and psychologically), getting inside the life of another, and/or allowing another to cross one's personal boundary (Register and Henley 1992). Self disclosure demands a certain degree of trust in the other and making oneself vulnerable. Furthermore, disclosing personal details often leads to an increased level of self-disclosure from an intimate other (Duck 1988). Thus, self-disclosure is an effective mechanism for maintaining and changing the level of intimacy in a relationship. Disclosing too little or too much can either escalate or de-escalate a relationship (Robson and Robson 1998).

Presence is the subjective feeling of another person being present in either a physical and/or a non-physical manner (Register and Henley 1992). The feeling of presence can be triggered by symbolic actions of the absent one(s) or the feelings can emerge spontaneously without any (objective) external cause. Thus, while being very powerful and contributing strongly to the feeling of intimacy with another, the feeling of another person being *present in absence* is very complex, subjective, and sometimes highly irrational. A feeling of presence is not so much due to being physically co-located, but due to re-living the pleasure related to being in the company of another person (Register and Henley 1992). Complementing this view, other researchers note that presence goes both ways. They stress the importance of feeling *oneself being present to another* (in either a physical or a non-physical manner) for creating and maintaining intimacy (IJsselsteijn et al. 2003, Biocca and Harms 2002).

Cognitive intimacy reflects the depth of awareness and knowledge intimates have of one another (Moss and Schwebel 1993). Cognitive intimacy is characterised by feelings of 'knowing' the other. Intimate friends, dating partners and spouses typically develop deep cognitive understandings of each other, and often share a range of personal information and preferences. This includes knowing one another's principles, values, strengths, weaknesses, hopes, fears and idiosyncrasies (Altman and Taylor 1973). Also, it has been shown that increasing the amount of cognitively exchanged information between spouses increases the level of intimacy they experienced. Thus being able to establish and maintain a shared cognitive life is a major requirement for building and sustaining an intimate relationship.

Affective intimacy is the reception and expression of emotion (Moss and Schwebel 1993). Affective intimacy involves a feeling characterized by a deep sense of love, caring, compassion and positive attraction for one another. Affective intimacy reflects the depth of awareness intimates have of one another's emotional world and the emotional exchanges they share. The level of affective closeness in friendships, serious dating relationships or marriage, is commonly reported as closely related to the level of

intimacy of that relationship (Levinger and Senn 1967). Also, affective intimacy is often highlighted as a key differentiator between close friendships and relationships involving romantic love (Moss and Schwebel 1993).

Commitment is the extent to which partners in a relationship perceive their relationship as ongoing for an indefinite period (Chelune et al. 1984). Commitment includes acts intended to grow or maintain intimacy. Being in a committed relationship generates strong feelings of cohesion and connection (Moss and Schwebel 1993). Commitment is an important foundation for intimate relationships and often a precondition for other aspects of intimacy (e.g. self-disclosure) to flourish (Chelune et al. 1984). Misunderstandings in the expression of commitment and changes in one partner's belief in the commitment of the other may impede the growth of an intimate relationship or initiate its decline (Chelune et al. 1984, Duck 1981). Thus, being able to convey and experience commitment constitutes a crucial requirement for building and sustaining an intimate relationship.

Mutuality is considered the centre of any intimate relationship (Cheal 1987, Chelune et al. 1984). Mutuality is the assumption that intimate partners are co-engaged in a common cause. Mutuality originates from a process of exchange, interdependence and reciprocal expectations (Moss and Schwebel 1993). Mutuality exists when gifts or symbolic signs of value are exchanged (Cheal 1987). Mutuality is characterized by a sense of fairness shared by both partners in relation to the rewards and costs of their interactions (Chelune et al. 1984). While mutuality implies joint and shared interactions, it does not necessarily require similar or identical patterns of interaction. Rather, intimate relationships may involve both reciprocal interactions (partners showing similar behaviour) and complementary interactions (partners showing different behaviour that complements each other).

We believe these eight aspects of intimacy are useful for understanding how intimacy is constituted. However, it is important to note that these components do not exist or work independently, nor do they individually satisfy the intimate experience. Indeed, the themes overlap greatly and are highly interrelated (Moss and Schwebel 1993). The themes discussed above suggest that intimacy includes both a behavioural and an emotional level involving, on one side, *actions* caused by or causing a feeling of intimacy (such as mutuality, self-disclosure, non-verbal communication or physical intimacy) and, on the other side, *feelings* of intimacy (such as affective intimacy, cognitive intimacy, presence or commitment) caused by or causing these actions. Thus if technology is to support the mediation of an intimate relationship, it needs to facilitate these behaviours and emotions.

3. PROBING INTIMACY

This paper addresses the challenge of investigating intimacy and designing interactive technologies to support intimate acts. Our approach is a combination of ethnographic techniques and participatory design approaches that allow us to collaborative explore the phenomenon with a small group of 'participant-research' subjects. To this end we have adopted the 'cultural probes' techniques developed by Gaver et al. (1999) and the

Equator team (Cheverst et al. 2003) and extended them with contextual interviews (Beyer and Holtzblatt 1998). Cultural probes are a novel collection of techniques gaining prominence in interactive systems design. They are particularly suited to investigating people's everyday life in situations difficult to reach with traditional social science methods such as questionnaires, interviews, focus groups or participant-observation. Probes are designed to prompt and elicit information from people about their lives and 'local culture' (Gaver et al. 1999). In particular, probes are designed to garner an understanding of the playful character of human life and the multifaceted ways people 'explore, wonder, love, worship, and waste time' (Gaver 2001). Cultural probes gather insight from within the site in question, with the full cooperation and involvement of the participants concerned. The insights are gathered as activities are performed and while technology is in use, thus maintaining 'fidelity to the phenomenon' under investigation (Crabtree et al. 2003).

Like deep sea or planetary probes, cultural probes are 'sent-out' by researchers and return fragmentary data over time. Rather than relying on the presence and intervention of the researcher, cultural probes are designed to encourage and empower subjects to collect data themselves (Arnold 2004). This allows the collection of data from situations where researcher presence is problematic by giving participants the means to record everyday activities as they occur or shortly afterwards. It also allows research materials to be collected over longer periods in multiple locations compared with resource intensive methods such as traditional ethnographic approaches.

3.1. Cultural Probes

We assembled a collection of cultural probes into a 'probe pack' (figure 1) containing:

- Two scrapbooks providing the participants with an open format for creative and rich descriptions of both current practice and imagined future technologies
- Two diaries (one for each partner) allowing the participants to individually describe the temporal flow and routine of their lives throughout the period of study
- A digital camera and a photo printer allowing the participants to capture, print, edit and annotate up to 180 photographs for the scrapbooks, diaries and postcards
- Catchphrases (e.g. "I feel lonely when…" or "I really love it when…") printed onto sticky labels allowing the participants to stick them into the diaries or scrapbooks provoking reflection by the participants
- Various consumables including stamped pre-addressed postcards, coloured Post-It notes, pens, crayons, paper clips, glue and scissors etc. for use with the scrapbooks.
- Information for contacting the researchers via landline, voice-mail, e-mail and SMS throughout the study.

Probe packs were given to six couples. Participants were asked to use the probes to articulate the role technology played in their relationship. Probes were used to elicit: where, when, how and why they interacted; how they felt during interaction; and reflections on the usefulness of current technologies in these situations.

Figure 1. Contents of the probe pack

Figure 2. Scrapbook and diary from participants

The diaries were used individually to record daily communication and interaction activities. This included the form of communication (e.g. SMS) and other details such as time, date, location, the content and the feelings associated with it (e.g. urgency or dissatisfaction). The scrapbooks were used collaboratively to tell rich and evocative stories about communicative events and to express the technology wants, desires, likes and dislikes surrounding these events. Couples were encouraged to use coloured notes, pens, crayons, glue, photos, magazines clippings, drawings and so forth to form a montage of their intimate lives. The digital camera and printer were used to photograph and print significant events. The docking printer provided the immediacy of traditional Polaroid photographs with the convenience of lasting digital images. Participants were encouraged to take photographs of everyday artefacts or events that express some important dimension of their interactions: the answering machine at the time of receiving some unexpected news or of a child in a football final to share with an absent parent. Participants were asked to print, to annotate and to cut and paste the photographs into their scrapbooks or diaries or postcard, as they saw fit (figure 2). Finally, the participants were asked to read and reflect on the catchphrase labels, complete them, and stick them into the diary, scrapbook or on a post card. The stamped postcards could be used for short stories or images to be sent to the researchers or intimate other.

It was stressed that nothing in the probe pack was compulsory. The instructions were only suggestions. All the materials could be used in whatever way they wished. No time requirements were made, but it was suggested that the participants should spend about 20-30 minutes each day using the probe pack materials.

An additional probe element was introduced midway through the study. This new element consisted of small printed facsimiles of a variety of mobile device screens (e.g. mobile phones and personal digital assistants). This new element served to both refresh participants engagement in the study and encourage them to envision possibilities for future technologies to support their relationship. Participants were invited to use these mobile device screen facsimiles to note design ideas and to insert them into the scrapbooks or diaries (see figure 4).

3.2. Contextual Interviews

Our study combined cultural probes with a series of contextual interviews (figure 3). These interviews gave participants the opportunity to explain, clarify and expand upon the materials they had collected and collated through their work with the culture probes. In these interviews, the probes became a starting point for a conversation between researchers and participants that revolved around the participant's relationship, and the roles played by technologies in mediating (or not) their intimacy. The probes recorded fragments that were used during interviews to prompt memory, seek explanation, and encourage reflection. Through these interviews we were able to uncover previously unarticulated aspects of their relationship and intimate behaviours, routines and habits. Participants and researchers worked together to develop a shared understanding of how the relationship 'worked' and the roles technologies played and didn't play in mediating their engagement with each other. Interviews also allowed regular contact between researchers and participants. These meetings were used to 'tune' participant's engagement with the probe materials. Meetings were used to check on participants understanding of the study, to gently steer them toward the intended focus of the study, to ask them to focus more on certain probe activities and to introduce additional tasks. Returning from these interviews, researchers brought back a wealth of data that fuelled ongoing discussion, reflection and analysis by the research team.

Figure 3. Contextual interview with participants

Figure 4. Participant's children playing with facsimiles

3.3. Participants

The study involved six mixed-gender couples in long-term, stable relationships. All couples cohabitated, although work related travel occasionally required periods of separation. The age of participants ranged from late 20's to late 40's. Three couples had children, ranging in age from 18 months to 12 years of age. All couples used a variety of electronic media such as landline and mobile telephony, email, chat, SMS and fax to communicate with each other, although the exact mix of technologies used by each couple varied markedly.

3.4. Procedure

The couples were recruited through a screening process involving an initial, informal interview. Couples were selected to give diversity in both family situation (no children, very young children, older children); the degree to which they used ICTs to communicate with one another (once or twice a day up to 20 or more times a day); and types of

technologies they used. Important in the selection of participants was the degree to which participants were willing and able to articulate, discuss and reflect on their relationship as well as their ability to engage in imaginative speculation about future ICTs. Two researchers were assigned to each couple and were responsible for introducing the cultural probe pack and conducting all contextual interviews with the couple. Interviews were predominantly conducted in the participants' homes, but some interviews were conducted at the University and several were conducted in a café. Choice of interview location was at the discretion of participants.

The cultural probes were deployed for a period of seven weeks. At the beginning of this period, an initial interview was carried out at the participant's homes. This included questions about the participants' backgrounds, their relationship, their communication habits and their use of technology. Following the interview, the researchers presented the cultural probe materials and instructed the participants on how to use them. After the first week of the study, the researchers visited the participants' homes again for a second interview. The purpose of this visit was to ensure the participants were 'on track' with the use of the probes and to investigate the activities of the first week through a conversation about the data collected in the diaries and scrapbooks.

Following the second interview, participants were left to work with the probe pack for three weeks, at which time, a third interview was conducted. The purpose of the third interview was to examine and review the materials collected through the probes since the last interview. Researchers and participants discussed the materials accumulated in the scrapbooks and diaries, and participants were invited and encouraged to clarify, elaborate and reflect on the materials they had recorded and composed over the previous three weeks. At the end of the third interview session, researchers introduced the small printed facsimiles of mobile device screens. Participants annotated these facsimiles to explore novel designs in situations where current technology inadequately supports personal communication and interaction (figure 4). After the third interview, the participants were again left to work with their probe materials for three weeks. In the fourth and final interview, researchers discussed the diaries, scrapbook and other materials composed over the previous three weeks. In addition, researchers and participants discussed design ideas produced on the mobile device screen facsimiles. This interview was also used to bring closure to the seven-week process. The researchers retrieved all materials gathered through the cultural probes at this time. It is our intention to return the probe pack diaries and scrapbooks to participants as a 'gift' after our analysis of the material is completed (copies will be retained for our records).

4. RESULTS

The contents of the scrapbooks, diaries and interviews were reviewed and discussed on a weekly basis by the research team. On the basis of our analysis of material collected in the first four weeks of the study, we present some preliminary findings.

A theme occurring across all couples was a strong need to support *presence in absence.* This is a feeling that the other is present, even though they may be far away. This is closely related to the issue of *presence* discussed earlier. Participants identified

a desire to be in contact with each other while physically separated. This does not only happen when one partner is away for a long period of time, it also occurs during ordinary workdays, sometimes with only minutes separation. For example, couples who work in office buildings a few blocks apart or couples who work on different floors of the same building are in regular contact, up to 10 times a day, via phone, SMS, or email. Often the messages play the dual role of organising family affairs (e.g. "Who is picking up the children?" or "What is planned for dinner tonight?") and for declaring a caring presence ("I am here, thinking of you"). Other examples of creating presence-in-absence are through indirect, non-verbal communication "by proxy", for example, one partner preparing breakfast for the other before leaving for work. Presence is not only created by exchanges of message. Artefacts themselves carry presence. Merely carrying a mobile phone, because it affords the opportunity for immediate contact if desired, creates a sense of presence and feelings of security and comfort. Furthermore, absence need not be physical. In some instances, couples who were physically nearby but engaged in separate activities supported presence-in-absence by communicating with each other using SMS from the lounge room to the bed room or email from one side of the room to the other. In these examples, physical presence did not compensate for emotional absence. The couples felt a desire to be more present than afforded by physical closeness. This desire was mediated by technology.

Our study suggests that much of the communication that passes between intimates is *emotional rather than factual.* While intimate communication is not 'fact free' it often plays a role more akin to 'stroking and patting' than verbal conversation. The messages are often information poor, but laden with significance. Examples include spontaneous gift giving, messages of affection, flirtation, telephone calls to chat about nothing in particular. Many of these interactions serve to confirm that a person is thinking about, caring for and aware of their partner. It is often the act itself, rather than the explicit message it carries, that is significant.

Intimate acts are often *ambiguous and incomplete*, suggesting and hinting rather than explicating in detail. They occur in the context of a rich, shared and sometimes idiosyncratic view of the world. This *shared world view* is vital to feelings of intimacy and is also a resource artfully drawn on by intimates during interaction.

It comes as no surprise that our study indicates that intimate acts are often *private*. Our results suggest privacy has many dimensions. For example, intimacy entails *self-disclosure*. Intimates reveal something of themselves to each other and they may feel vulnerable if their interactions are exposed to the gaze of outsiders. As a result, intimate acts are often constructed to be hidden from the view of others. Participants in our study were selective in the communication media they choose for interaction, and partly based these decisions on their perception of the privacy and security of the various communication channels at their disposal. For example, some did not use work-based email for certain intimate exchanges because they were aware that system administrators can view their emails. Similarly, intimate information was not disclosed while on a crowded but quiet train car or over the telephone in an open plan office. Some participants, particularly those who regularly used workplace technologies to

communicate with each other, reported taking efforts to obscure that they were engaged in communication with their partner.

Even when intimacy is displayed in public, these acts can be nuanced and imbued with *private meaning* difficult to see and interpret by outsiders. Some participants developed private 'codes' and short-hands to communicate with one another, such as an SMS of '146' for 'I love you' or calling the home telephone and allowing it to ring thrice at certain times of the day to signify 'I'm awake, I'm OK, I'm thinking of you'. Others engaged in flirting in situations were flirting was inappropriate – such as knowingly sending provocative SMS messages when their partner was in a work meeting – relying on the personal form of these messages to obscure their lack of proprietary. Some participants reported drawing on their *shared past* and detailed knowledge of one another to privately communicate in the full view of others, using oblique references that were presumably ambiguous or meaningless to others, such as when one end of a telephone conversation could be overheard. More generally, participants often drew on a repository of anecdotes, past conversations, knowledge of events and running jokes in their interactions. Indeed, much of what passes between intimates is unsaid and premised on deep knowledge and understanding of one another.

Actively constructing and maintaining a *shared history* was also important to participants. All participants collected mementos, photographs and other materials that evoked their past together. Some participants invested significant effort in constructing and maintaining these records in scrapbooks and photo albums, and often collaborated in reviewing and updating these repositories. These mementos were at once a public declaration of ongoing commitment and artefacts through which past intimate feeling could be rekindled. With the advent of digital photography, some participants had begun keeping digital archives of photographs burnt to CD-ROM for viewing and reviewing on the home DVD player, often as a joint activity.

Participants were also engaged in a *common journey* and shared the costs and rewards of lives together. Where a shared history brought comfort from the past, a common journey generates hope for the future. Both are related to the theme of *commitment*. Features of the participants' lives, such as raising children, caring for older family members, maintaining the household, or travelling to work, were all enterprises that were shared and, in the sharing, became vehicles for enacting, affirming and maintaining their relationship. Joint responsibility was taken for domestic life, including activities such as paying the bills, transporting children and preparing meals. These activities were often coordinated on the fly using interactive technology such as mobile phones. The division of labour within these relationships had regular patterns but was also fluid and renegotiated over the course of a day. In addition, responsibilities also provided occasions for affirming the relationship. For example, the success of a child at school was affirming "our" achievement as "good parents". Even activities that were the sole responsibility of one member of the relationship became joint enterprises. Participants reported drawing on their partner's help and skills for work related tasks such as database development, setting up a web-based email account or writing a job application. Being able to help and share common tasks affirmed the relationship and sense of moving through the world together as a team, rather than as atomised individuals.

Above all, our participants reported the need to find time to be *alone together* away from the hectic schedules of family and work related responsibilities that dominated their lives. Whether this time alone was found while driving a car with the children asleep, sharing a meal at the end of the day, or even working on separate projects but sharing the same physical space to do so, all felt that *physical closeness* was crucial to their relationship, and something that could not be adequately replaced or mediated by interactive technology.

All our intimate relationships involve expectations and assumptions about *reciprocity* and exchange between partners. In our study, we found interaction was founded on a *commitment* from both parties to reciprocate in both content and form. These expectations were nuanced, negotiated and arrived at over many years, yet remain fragile and are occasionally misjudged and misinterpreted leading to misunderstandings and conflict.

Our study has also taught us that it is important not to romanticise intimacy. Intimacy and the tight, emotionally charged bonds it entails, is fragile. While relationships may be robust, misunderstanding, and misinterpretations do occur. When they occur, these breakdowns can have serious repercussions; creating ill will and emotional hurt that can obstruct and undermine intimacy within the relationship. The fallout from a simple breakdown in understanding between partners can reverberate through the relationship for days, if not weeks. For these reasons, any interactive technology designed to support or mediate intimacy needs to mitigate against these forms of breakdown and allow for easy and rapid repair of them when they do occur.

Even though our results are still preliminary, they have given us a deeper understanding of how some of the themes identified in the literature contribute to intimacy, and how people use technologies to support and sustain them. Our challenge is to translate our observations and extended knowledge of the central themes to designs.

5. DESIGN IDEAS

We now present three preliminary design ideas that have been distilled from the data. The designs are intended to exploit opportunities for technologically mediating intimacy. The designs are not necessarily futuristic. Similar designs may already exist. It is not our intention to implement these design ideas in their current forms. Rather we intend to use the design ideas to seed ongoing design activities such as participant design workshops and scenario-based acting out (Howard et al. 2002).

Memorabilia Manager: Couples spend a great deal of time and energy organising their personal mementos. These are typically photographs and videos, but often include other items such as tickets (e.g. airline ticket from a honeymoon) and souvenirs (a sea shell from that special holiday). These have important value for intimate relationships. They signify common history and a shared journey and contribute to the broad theme of commitment. A 'Memorabilia Manager' should be very portable and allow the experience of creating and reviewing the memorabilia. It would allow couples to compose digital and non-digital forms into a meaningful mosaic. It would be a type of 'family blog' that facilitates simple recording of family events.

Constant Touch: Face-to-face communication was regarded by all participants as an authentic experience, while mediated interaction as somewhat impoverished, thin and 'abstracted'. However, when face-to-face interaction was not possible (or practical) intimates desired connectedness and presence. 'Constant Touch' is akin to walkie-talkie or 'push-to-talk' devices (Telstra 2004). It provides an open channel for constant updating throughout the day. It may contain a single point transducer (such as a light) that is activated when one wants to say "I'm thinking of you". The form is configurable to suggest a physical presence as if "She is with me all the time".

Family Digital Assistant: If a family had children, then the children tended to dominate all activities – including intimate ones. Children were an anchor to the family's life and a key mediator for the expression of intimacy. Rather than finding intimacy beyond family duties, it was through the routine of child-raising that intimacy was expressed. The 'Family Digital Assistant' (FDA) acknowledges that shared mundane experiences are part of the intimate experience. Where a PDA is for personal purposes, a FDA coordinates family activities. We observed that poor coordination can lead to emotional hurt and bad tempers. The FDA is a response to this need.

6. CONCLUSIONS

Intimate relationships involve an intricate and nuanced dance between partners involving a complex array of varied activities. Many of these take place in close physical proximity and involve touch and face-to-face communication. Others are mediated across space and time and involve activities such as talking on the phone or writing letters and postcards. While mediating intimacy is not a new phenomenon, new technologies influence how, when and why we interact with each other. However, little is known about the adoption and use of these technologies within intimate relationships and even less is known about how, when and why they provide good support for mediating intimacy and how, when and why they fail.

Perhaps more than the majority of domestic acts, intimacies display fragility when under examination. In this paper we have described an approach to the study of intimacy that stressed the need to empower participants; providing them with means to record intimacies during or soon after the acts themselves and means to describe intimacy in their own words. We have stressed the importance of hearing the 'voice of the intimates' given our current lack of understanding of this new domain of HCI. Although we have largely limited our report of our preliminary findings to the analysis and description of current practice, our approach has also aimed to be playful; we have worked to encourage and legitimise participants' exploration of possible futures, rather than strictly limiting them to reporting on their current practice. The insights generated through this playful imagining will be the topic of subsequent work.

ACKNOWLEDGMENTS

The authors would like to thank all couples participating in the study and acknowledge the support of the Smart Internet CRC and the Danish Technical Research Council (project reference 26-03-0341).

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Chapter 6

Work context

Jesper Kjeldskov and Jan Stage

Abstract. Communication between physically distributed people in industrial and safety-critical domains is often spoken and mediated through walkie-talkies, or closed-circuit intercoms. Because this kind of communication is hampered by noise, radio interference, lack of persistency etc., vital information is sometimes lost. In response to this challenge, this paper discusses the use of "canned" text-based messaging as a supplement for improving such communication. Based on data from ethnographic studies of work activities in an industrial domain, and grounded in a theoretical model of communication, we have designed and evaluated a mobile canned communication prototype system facilitating exchange of predefined text messages, a persistent graphical representation of the operation in progress, and a filtered list of completed tasks. Results from two evaluations show that in the domain considered, canned text-based communication has a potential to supplement voice and assist in overcoming some of the inherent problems of spoken communication. Yet using a textual and persistent mode of communication also raises new challenges such as choice of modality, speed, flexibility and handling situations deviating from standard procedures.

1. INTRODUCTION

Industrial domains are potentially interesting areas of applications for mobile information and communication technologies. Work activities in industrial domains often involve a number of distributed collaborating actors who are mutually dependent on access to computer systems remote from their current location and on knowledge about the activities and strategies of their co-workers. Typically this is supported only by spoken communication mediated through mobile phones, walkie-talkies or closed-circuit intercoms. As spoken communication is highly sensitive to noise, radio interference, interruptions, lack of persistency etc., vital information may be lost in the transmission or missed by the receiver(s).

Originally published as Kjeldskov, J. and Stage, J. (2006) Exploring "Canned Communication" for Coordinating Distributed Mobile Work Activities. *Interacting with Computers,* 2006(18), 1310-1335.

Previous research has to some degree dealt with the extent to which distributed mobile users in industrial and safety-critical domains can benefit from handheld computer systems in situations where actors are concerned with computerized information and processes of critical importance remote from their current location. Examples include the use of mobile multimedia communication for telemedicine and early diagnosing in emergency ambulance services (van den Anker and Lichtveld 2000), distributed process control and error diagnosing in wastewater treatment plants (Nielsen and Søndergaard 2000), and the use of remotely controlled service robots for aiding disabled or elderly people (Hüttenrauch and Norman 2001). Also related to this, the limitations of voice-based communication by capturing spoken utterances and integrating it with other data for creating persistent graphical representations have been suggested within areas such as air traffic control (Fields and Paterno 1999), and fire-fighting (Champ et al. 2000).

In response to this growing area of interest within HCI, this paper explores the supplementary use of text-based "canned communication" in a prototype system for coordinating work activities on large container ships: the Handheld Maritime Communicator (see figure 1). The idea for the Handheld Maritime Communicator emerged from a multidisciplinary research project involving an ethnographic field study on work activities in the maritime domain involving computerized process control and information systems (Andersen 2000, Nielsen 2000). On the basis of this field study, we explored the usefulness of handheld computers for supporting communication by complementing existing spoken communication with the use of predefined (or "canned") text-based messages similarly to the way SMS and e-mail applications on mobile devices complement people's voice-based communication.

Figure 1. Canned communication on a mobile device for use on maritime bridges

In the study reported in this paper, we describe and discuss the lessons learned from a first step in the direction of "canned" communication aids designed for overcoming some of the limitations of spoken communication in industrial domains by supplementing it with a textual and persistent channel. Hence the aim of the study presented in this paper has not been to develop a final solution to a well-defined problem and deploy this solution in the domain studied, but to gain experience with and a deeper understanding of the use of canned textual communication as a supplement to spoken commands. This is done through experimental design and evaluation of a prototype system – using the prototype system as a sort of "technology probe" (Hutchinson et al. 2003) to prompt and study new communicational behaviour. This aim has influenced our research in several ways. Firstly, we did not try to change the structure and content of what was being

communicated but intentionally replicated this directly in the prototype system focusing solely on the changed modality of these utterances (from audio to text) and the use of pre-defined commands (communication canning). Secondly, we did not pursue research into issues such as the physical form factor of the mobile communication device facilitating use in a potentially harsh outdoor environment, and the technical implementation of a network infrastructure working robustly within a physical environment dominated by large amounts of metal. We acknowledge that these (and other) issues are highly relevant for the development of new communication device solutions for the industrial domain, and welcome further research into these specific areas complementing our own endeavours within the use of canned textual communication.

In section 2, we introduce the industrial domain studied and the specific work activities supported by our prototype system. This includes highlighting findings from the field studies related to limitations in current means for communication and coordination. Section 3 presents our analysis of the field data. In section 4, we present the details of the design of the Handheld Maritime Communicator prototype, and in section 5 we present two evaluations involving usability experts and prospective users. The findings from these evaluations are discussed in section 6. Finally, section 7 concludes on our study and point out avenues for further research.

2. FIELD STUDY OF WORK ACTIVITIES

Maersk Line operates some of the world's largest container vessels of sizes equivalent to the length of five Boeing 747-400 Jumbo-Jets (figure 2). The operation of such vessels requires workers to be highly mobile and physically distributed. At the same time, however, work activities are often related to the use of computer systems located centrally on the ship. Thus a strong motivation exists for exploring the use of mobile computers for supporting distributed work activities in this domain. Designing useable mobile computer systems for the maritime domain is not trivial. Work activities on large container vessels are typically safety-critical and involve high risks in the case of errors. Especially when manoeuvring inside a harbour, erroneous actions may result in the vessel running aground, into the quay, or colliding with other ships. In either case, this would cause serious material damage, potentially severe injuries on personnel, and possible loss of human life.

Figure 2. Sine Maersk (347 m. long and 43 m. wide) in Gothenburg Container Terminal, Sweden

Qualitative investigations into work activities on a Maersk Line container vessel were carried out (Andersen 2000, Nielsen 2000). This included ethnographic observations of the application domain and interviews in situ from several voyages along the coastline of Europe. The field studies were documented through written notes and video recordings capturing overall views of the captain, harbour pilot and officers on the bridge as well as close-up views of the interaction with key instruments. The audio channel captured interpersonal communication on the bridge and VHF radio communication with the distributed crewmembers. In order to facilitate systematic analysis, a person with detailed insight into the application domain transcribed a selection of the video recordings. A partial transcription of the recordings from one short voyage within Europe amounts to approximately 200 pages.

Apart from informing new interface design for existing maritime instruments (Andersen and May 2001) a number of work activities were identified in which the use of mobile computer terminals could be desirable. These included diagnostic and maintenance work in the engine room, surveying the condition of reefers during voyages, locating personnel in case of accidents, and supporting various distributed collaborative work activities. Of particular interest to the interviewed crewmembers, our attention was brought to the processes of departing from and arriving at harbour including the operation of *letting go the mooring lines* before leaving the quay because this operation requires a high level of communication within a predefined pattern between actors that are physically distributed on the vessel. Currently, this communication is based on spoken commands being transmitted through handheld VHF radios. Through analysis of several video recordings and interviews with officers and captains, a series of limitations in the present means for communication and coordination were brought to our attention, some of which could potentially be overcome by the use of mobile computer technology. Project stakeholders from Maersk Line and the participating university researchers therefore agreed that supporting this particular operation would be a suitable starting point for experimenting with the use of canned text-based communication.

In the following sub-sections, the operation of letting go the lines as experienced through the field studies is described in detail. This description served as an overall context for the use of the envisioned Handheld Maritime Communicator and outlined a number of challenges, which had to be addressed in the design of the prototype.

2.1. The operation of letting go the lines

When a container vessel is ready for departure, the first step in leaving the quay is to let go of the mooring lines that are holding the ship in position fore and aft (figure 3). However, as physical space is restricted and means for precisely manoeuvring large vessels are limited, all lines cannot simply be released simultaneously.

When a line is let go, it will remain in the water for a period of time during which no means of propulsion is available due to the risk of lines getting sucked in and wrapped around a propeller or thruster. During this time, the vessel can only be manoeuvred by means of the remaining lines. Consequently, lines are released sequentially in accordance to specific need for manoeuvring in a given situation.

Figure 3. The aft mooring lines of Sally Maersk (sister ship of Sine Maersk)

Due to the huge size of the vessel, the work tasks involved when letting go the lines are distributed among a number of mobile actors located at strategic positions, as annotated on figure 2. On the bridge (1), the captain and other personnel control the rudder, propeller and thrusters. Fore (2) and aft (3), the first and second officers control the winches for heaving in the lines. Ashore, two teams of assistants lift the lines off the bollards. To insure the safety of the operation, individual work tasks are carefully coordinated and carried out under strict command of the captain in charge.

At present, communication between co-workers is spoken. While people on the bridge can see and hear each other directly, personnel on deck are, however, out of direct visual and audio contact and have to communicate with the captain via walkie-talkies. In order to carry out the operation of departure in a safe manner, the captain needs an overview and total control over the propulsion, direction and mooring of the ship. While information about the rudder, propeller and thrusters are available on dedicated instruments on the bridge no information about mooring is available. At present this information only exists as a mental model in the head of the captain based on his perception of the ongoing communication between bridge and deck. As this mental model is highly sensitive to errors or misunderstandings in the ongoing communication between bridge and deck, and since disparity between the captain's mental model and the real world may cause wrong decisions to be made, considerable cognitive resources are spent on establishing and maintaining *common ground* (Clark and Schaefer 1989) among the cooperating actors. By common ground, we refer to the principle of entering and maintaining a stage of mutual knowledge, beliefs, and assumptions among communicating participants through a collaborative process of *grounding,* during which common ground is updated in an orderly way, by each participant trying to establish that the others have understood their utterances well enough for the current purposes (McCarthy et al. 1991). While it has been pointed out that it is not necessary to fully ground *all* aspects of a conversation, it is essential that *"The contributor and the partners mutually believe that the partners have understood what the contributor meant to a criterion sufficient for the current purpose"* (Clark and Schaefer 1989:262). What constitutes this criterion, of course, depends on the context of the situation and will necessarily vary with the collaborators' goals. As a part of the process of grounding, communicating partners have different means of providing evidence of mutual understanding including displaying what has been understood, acknowledging utterances, continuing with the next expected step of a given process, as well as continued attention to the conversation.

Supporting reaching and maintaining common ground, established rules and formalized procedures exist for oral communication such as, for example, confirming status reports and commands by repeating them back to their sender. However, as the size of vessels and the use of technology increases so does the complexity of systems controlling the ship and the cognitive overhead and amount of parallel tracks of communication required for its operation.

2.2. Findings from field studies of "letting go the lines"

Through analysis of video recordings, transcriptions, and interviews with officers and captains, a number of key limitations experienced in the use of spoken communication for coordinating collaborative work activities were brought to our attention:

- Sound quality is often poor
- Communication is not persistent and
    - cannot be automated,
    - is time consuming,
    - suffers from bottlenecks on the bridge (multiple parallel tracks),
    - suffers from language barriers,
    - lacks integration with other systems.

As walkie-talkies and VHF-radios often lack sound quality, workers reported that misperceptions and misunderstandings between the actors often occur due to incomprehensible messages. This leads to a need for repeating statements and meta-communicating. Due to the ephemeral nature of spoken communication, the workers also reported that messages were easily and frequently missed because they were only available during the limited period of time when they were "in the air" and were not persistent. After an utterance had been communicated the information only existed in the memory of the actors taking part in the interaction and was not publicly available for others who had not received the utterance when first stated. In addition to this, workers reported that spoken coordination could not be automated but involved actors remembering sometimes highly complex workflow and continuously deciding for whom specific information may be relevant at which time. Workflows coordinated through spoken communication are hard to support and reducing the coordination workload was reportedly difficult. Workers also stated that spoken communication was very time consuming and that they tried to minimize time spent on communicating in order to maximize the time available for work tasks. As a part of this, workers reported that they would sometimes cut messages short and only communicate fragments of information and rely on implicit meaning in the given situation. While known for limiting the "air time" of communication this approach was also known for sometimes leaving people confused about the meaning of utterances requiring explanations and meta-communication. The use of spoken coordination was also reported to suffer from different types of bottlenecks. One type of bottleneck reported by the workers consisted of multiple people talking on top of each other on the same channel resulting in communication being cut up, and information being missed. Another, and more complex, bottleneck reported by

the workers consisted of multiple parallel tracks of communication across different communication channels (e.g. radio messages between bridge and deck disturbing communication between people on the bridge and visa versa) complicating the regulation of turn taking. Due to the international nature of the domain, communication on board container vessels is usually conducted in a language different from the language being used by the local harbour pilot to communicate with other pilots, the pilot boat, tugboats, vessel traffic service etc. This results in the captain having limited immediate insight into the domain of the harbour pilot and vice versa and introduces a need for ongoing translations between the captain and the harbour pilot. Finally, workers raised the issue that information delivered through spoken communication cannot be integrated with the vast amount of other information sources in the ship's computerized systems. While the captain can, of course, take spoken information about, for example, distances, angles etc. to objects in the vessels immediate surroundings into consideration when looking at other instruments, this kind of information cannot automatically be made part of the computations regarding the ship's movements performed by the systems on the bridge. As a result, it was reported that the spoken information is usually not utilized to its full extent because it demands too many cognitive resources.

While some of these observed limitations may be unique for the studied context (e.g. language barriers), others apply generally to spoken communication within industrial domains. Overcoming or reducing these limitations served as an overall motivation for the experimental design of the Handheld Maritime Communicator.

Inspired by, amongst others, chat applications, newsgroups and Short Messaging Service (SMS) we speculated that a possible supplement to the present use of spoken communication could be the use of predefined, canned text messages on mobile devices. Hence, text offers some advantages over voice, it is a flexible communication channel requiring low cognitive overhead (Churchill and Bly 1999; Popolov et al. 2000), and it is not subject to the ephemeral nature of spoken utterances but is persistent. Furthermore, text-based communication can be done asynchronously as it fits in with other tasks or threads of communication and is not influenced by, for example, noise. On the basis of this, it was our expectation that some of the identified limitations could be eliminated or reduced by means of exchanging canned text-based messages and as a result more cognitive resources would be available for the other operations.

3. ANALYSIS OF COMMUNICATION

Motivated by the initial findings from the field study described above, we revisited the video recordings to investigate more thoroughly the communication and coordination of work activities related to the operation of letting go the lines and identifying structures and properties, which could help us overcome the identified limitations. Guiding this analysis, we focused particularly on the overall challenge of achieving persistency in communication.

Achieving persistency in communication means capturing the utterances of a conversation for later access (Erickson and Herring 2006). While audio or video recordings of spoken conversations can preserve a very rich picture, textual transcriptions capture

the essence, are highly concentrated, and facilitate fast browsing. On the downside, raw transcriptions offer little support for linking related utterances and maintaining overview of present state or outcome of parallel tracks of conversations. This is similar to textual communication in chat-like applications where achieving common ground can be problematic as discussed in McCarthy et al. (1991). On mobile devices the usefulness of raw textual transcriptions is further limited by small screen sizes. By relatively simple means of formalization, however, some of these problems may be solved. Based on the analysis of our video recordings and guided by literature on the topic, we found that at least three properties of conversations exist, which may be used for improving the representation of textual communication on a mobile device: 1) the aspect and tense, 2) the object and 3) the structure of conversations.

3.1. Aspect and tense of conversations

On an overall level, a conversation can be categorized by aspect and tense (Andersen, 2000), hence, a conversation is either imminent (future tense) executing (present tense) or ended (past tense). While executing (present) conversations are still open for negotiation, ended conversations imply some kind of mutual agreement having been made among the communicating parties. Though the process by which this agreement was reached may be of interest, the essential properties of ended conversations are typically their outcome. Imminent (future) conversations are characterized by potentially being initiated when and if appropriate in relation to preceding conversations (ended and executing). In relation to interface design for persistent communication, this categorization enables us to separate different conversations and differentiate priority. In some situations, ended conversations may be important, while in others only executing tracks are of interest.

3.2. Objects of conversations

Communication consisting of a number of interweaved tracks of conversations can be difficult to overview when sorted from the sequence of utterances. This can be illustrated with the following transcription extract of three conversational tracks taking place in parallel:

```
1     <Captain>                you can let go the bow line
2     <1st officer>            let go bow line
3     <Captain>                and you can take the stern spring
4     <2nd officer>            letting go stern spring
5     <1st officer>            bow line let go
6     <Captain>                bow line let go
7     <2nd officer>            and stern spring let go
8     <Captain>                stern spring let go
9     <Captain>                you just let go the stern line also
10    <2nd officer>            let go line aft
11    <1st officer>            and we have the bow line home
12    <Captain>                ok
13    <2nd officer>            and all let go aft
14    <Captain>                all let go aft
```

Sorting these utterances by the objects of communication rather than their sequence, the following structure appears:

```
1     <Captain>                you can let go the bow line

2     <1st officer>            let go bow line
5     <1st officer>            bow line let go
6     <Captain>                bow line let go
```

```
11    <1st officer>          and we have the bow line home
12    <Captain>              ok

3     <Captain>              and you can take the stern spring
4     <2nd officer>          letting go stern spring
7     <2nd officer>          and stern spring let go
8     <Captain>              stern spring let go

9     <Captain>              you just let go the line aft also
10    <2nd officer>          let go line aft
13    <2nd officer>          and all let go aft
14    <Captain>              all let go aft
```

Grouping text in accordance to object rather than sequence thus enables the creation of a more comprehensible representation of communication threads as seen in e.g. email and newsgroups (Popolov et al., 2000). Designing for the limited space of a mobile device interface this principle is valuable, as it requires little or no extra space compared to the raw transcription. For a richer representation of sequence, absolute timestamps or timers may be needed.

3.3. Structure of conversations

A number of computer systems for communication have been designed on the basis of speech-act theory (see e.g. Winograd and Flores 1986, Frisse 1988, Alm et al. 1992; De Michelis and Grasso 1994, Jayaweera et al. 2001, Akhus 2001). The basic idea of these systems is that conversations follow an overall structure of recurrence. Formalizing and modelling this structure in a computer system, the state of a conversation and possible speech-acts at a given time can be identified. According to Winograd and Flores (1986:65), the basic course of a conversation for action can be described in a diagram with nine different states (figure 4).

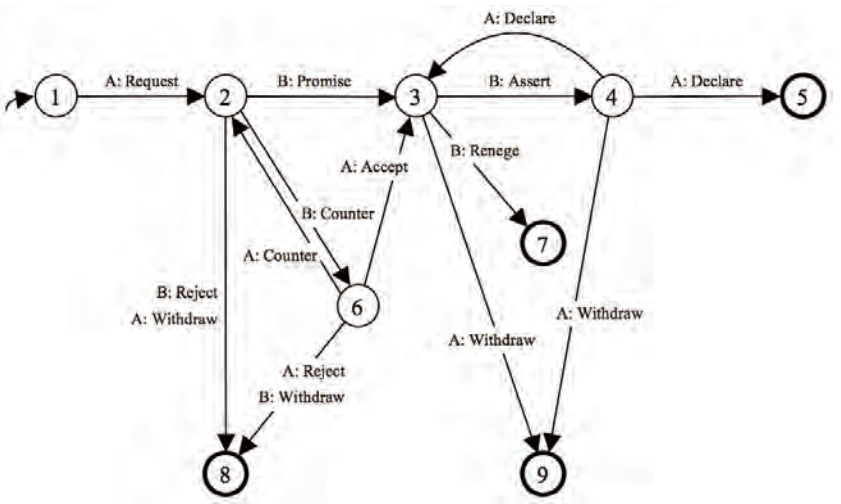

Figure 4. Winograd and Flores' conversation for action (1986)

The conversation for action model describes a generic pattern of communication, where one actor (A) makes a request to another actor (B). The model then describes how the conversation between A and B can develop over time through the performance of speech acts, resulting in a number of different intermediate states and end situations. As

emphasized by Winograd and Flores (1986), the relevant regularities proposed by this model are not in the individual speech acts (exactly what is being said and how it is being said) but rather on the overall level of the conversation, in which successive speech acts are related to each other. For more detailed discussion of the speech-act theory approach to conversation modelling, see, for example, De Michelis and Grasso (1994), Winograd (1994), Suchman (1994), Denning (2003), or Goldkuhl (2003).

While we did not originally analyze our empirical data with the conversation for action model in mind, an object-oriented analysis (Mathiassen et al. 2000) of the problem and application domain produced, among others, a series of state-chart diagrams depicting structures in the tasks and communication patterns, which we quickly recognized from the work of Winograd and Flores (1986). Re-examining the video recordings in the light of the conversation for action model it became evident that the conversations taking place on the container vessel during the operation of, for example, letting go the lines, could indeed be mapped on to this structure. Hence, the conversation for action model was not enforced on the empirical data but emerged out of it. However, we also found that the recorded conversations between the distributed actors on the container ship did not involve rejection, withdrawal or counter orders. Thus states 6-9 in figure 4 were not encountered in our field data. This was highly unexpected, but was confirmed by reviewing all transcripts of real-life casting-off operations (as well as other operations) and through interviews with domain experts. When asked about this issue, one of the captains stated that "when I give an order, I mean it, and it is not up for negotiation". Discarding the options of rejection, withdrawal or counter orders, we thus reduced Winograd and Flores' conversation for action model to a five state model corresponding to the formalized procedure for communication about "execution of a direct command" observed in our field studies (figure 5).

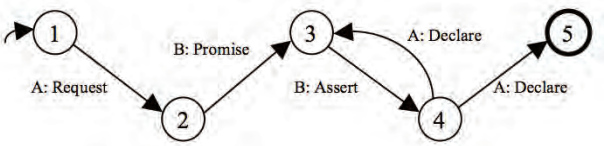

Figure 5. Execution of a direct command

The model of executing a direct command depicted in figure 5 applies to each track of conversation in the transcription from the field study above. Firstly, A requests the execution of a task (e.g. "you can let go the bow line"), which B promises to fulfil ("let go bow line"), taking the conversation to state 3. Having fulfilled the request, B asserts to A that the execution of the task has been completed ("bow line let go"). Finally, A declares contentment ("bow line let go"), and terminates the conversation (state 5) or goes back to state 3, waiting for additional asserts from B ("and we have the bow line home"). Note that states 1 and 5 in this diagram correspond to the categories of imminent and ended conversations. States 2 to 4 correspond to executing conversations.

Formalizing a conversation in relation to a structure such as the general conversation for action model (figure 4) or the execution of a direct command model (figure 5) has a number of advantages in relation persistency and "canning" of communication. First

of all, knowing the state of executing conversations, this can be represented visually for persistent and fast access: has a request been met? has an agreement been made? etc. This information can then be integrated with other data sources on the bridge. In relation to canning communication, possible future utterances may be deduced and prioritized over others in the form of predefined standard phrases as seen on some SMS-enabled mobile phones. Thus demands for user-interaction may be simplified and reduced.

4. CANNED COMMUNICATION PROTOTYPE

Informed by the three principles described above, we designed and implemented a functional prototype, the Handheld Maritime Communicator, exploring the use of canned communication for supporting the operation of letting go the lines. This section describes the design of the prototype system.

The prototype was implemented in Microsoft eMbedded Visual Basic allowing it to work on any PDA running the Microsoft PocketPC operating system such as the Symbol PPT8800 industrial PDA series (figure 6). Apart from a touch screen, such industrial PDA's typically support interaction by means of large rubber buttons located below the display and suitable for one-handed interaction. Due to the potentially harsh conditions of the use domain, we decided that all interaction should be facilitated by the use of these buttons. On the Symbol 8800 this would mean that the two-way button would browse the list of possible commands and clicking on the large button below it would select the highlighted item. Though aware of the fact that the final system would probably need to run on a custom-built, solid and weather resistant device and also have a built-in radio for voice-based communication in emergency situations, we decided that for a proof-of-concept prototype, experimenting with off-the-shelf hardware would be sufficient.

4.1. System architecture

The application running on the captain's device works as a server containing a formalized representation of the operation and patterns of communication. All other devices (for example those on deck) log on to this server and identify their physical location following which an appropriate interface is displayed on them. During the operation, function calls and unique command identifiers are exchanged in real time over the network. Thus the problem of commands being missed in the air due to poor sound quality is eliminated. All network communication is broadcast to all devices on the network but processed and represented differently on each device in accordance with their physical location (bridge, fore or aft). While on the first prototype the devices all displayed the same representations (but different possible commands), this architecture would make it possible for us to change the representations and modality used on each individual device, in accordance with, for example, the location of the user, in future iterations without having to change the underlying code. Also, another feature of the exchange of unique command identifiers is that the desired language can be defined individually on each device, thus reducing potential language barriers between co-workers by commands being automatically translated. The desired language is specified in a simple text-file on each device and is thus easily extendable and modifiable.

4.2. Interface design

The Handheld Maritime Communicator prototype (figure 6) gives distributed workers on the container vessel access to a mobile text-based communication channel and provides a graphical representation of the ship and its mooring lines. Supporting bystanders "listening in" on the communication, all communication is broadcast on the network as it unfolds. The overall design was based on two key ideas: 1) to supplement verbal communication with exchange of predefined, canned, text messages, and 2) to provide a simple representation of the work activities in progress in order to improve the distributed co-workers' reasoning about the ongoing operation as suggested by Rasmussen (1983). This supports human interaction rather than total system automation as discussed by Norman (1990). Meeting these suggestions, we designed an interface providing the user with access to a graphical representation of: the operation in progress; multi-threaded textual communication; a filtered list of completed tasks; and a selection of canned communication utterances.

Figure 6. The Handheld Maritime Communicator on a Symbol PPT8800

The interface is divided into four sections resembling the tense of conversations:

1. Pictogram of ship and mooring (present);
2. List of completed communication threads (past);
3. List of ongoing communication threads (present);
4. List of unexecuted commands (future).

The user interface for the bridge is illustrated in figure 6. At the bottom of the screen (immediately above the navigation button) unexecuted pre-defined standard commands and pending confirmations are displayed on a list. The order of the list corresponds to the standard sequence of the overall operation, and possible utterances only appear when appropriate in relation to the state of the task and the location of the specific device (bridge, fore or aft). By default, the most likely next step of the operation is highlighted. The list can be browsed with the navigation button and the highlighted utterance is

executed (sent) when pressing the select button. When a command is executed, it is removed from the list and the most likely next step is highlighted (as illustrated in figure 7). Thus the interaction required during standard procedures is limited to a minimum.

Figure 7. Executed commands being removed and new commands appearing

The list of ongoing tasks is perhaps the most important element of the interface. Here, inspired by newsgroups and multi-threaded chat applications, ongoing threads of communication are represented textually. As suggested in the discussion above, executing (present) conversations are grouped in accordance to the object to which they refer rather than by sequence (figure 6). Displaying parallel communication threads textually this way reduces the bottlenecks observed when multiple people speak simultaneously.

Figure 8. Commands being executed (a), confirmed (b), completed (c) and confirmed (d)

The representation of each thread of communication furthermore reflects the five stages of conversations for actions identified through the analysis. When a new command is executed (a request), it appears on the list of ongoing threads of communication representing uncompleted tasks. Next to it, a counter displays the time passed while waiting for confirmation (figure 8a). When a command is confirmed by repeating it back to the captain (a promise) the timer is substituted by the text "[ok]" followed by a description of the current activity (e.g. "Singling up..."). A counter next to this displays the time passed since confirmation (figure 8b). When a task is reported completed (an assert), a short statement (e.g. "1 and 1 fore") substitutes the description of activity and the captain is prompted for confirmation (figure 8c). When the completion of a task is confirmed by repeating it back to the deck (a declare) this is indicated by the text "[ok]" (figure 8d). As a feature of this design the list of ongoing tasks displays not only raw communication but also the present status of each command being executed.

When the captain confirms the completion of a task, the corresponding thread of communication is removed from the list of ongoing tasks and added at the bottom of the history list (figure 9). Hence it changes from present to past tense. The history list automatically filters itself to contain only the initiating commands and subsequent outcomes by removing information such as timers and confirmations (promises and declarations), thus reducing the complexity of the user interface. When the history list is full, it automatically scrolls the oldest commands and statements out of immediate sight. The list can be scrolled using the navigation button together with a function button.

Figure 9. Completed threads being added to history

At the top of the screen a simple pictogram graphically represents the lines attached to the quay for quick reference. Additionally, the overall status of mooring is shown textually (figure 10). This representation is generated from the formalized outcome of past and present threads of communication and supports different levels of abstraction in the interaction with the system. In future design, this information could be integrated with other systems on the ship or made available to others (e.g. harbour traffic control). While only containing redundant information that can also be deduced from the textual descriptions on the display, the graphical representation facilitates an overview of the present situation, which is not currently available on the vessel.

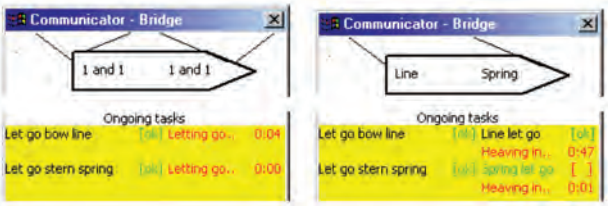

Figure. 10. Pictograms of current status of mooring

The interfaces on deck are very similar to that on the bridge thus providing the first and second officers with a view of the present status of the mooring and a list of all past and ongoing communication among the distributed actors. In the list of ongoing tasks, however, officers on deck are requested to confirm commands executed by the captain such as “let go bow spring”. Correspondingly, the list of pre-defined commands only contains those appropriate at the specific location at given states of the operation – e.g. “confirm: let go bow spring” for confirmation of the latter command or “spring let go” for reporting the completion of this task.

5. EVALUATION STUDIES

Evaluating the use and usability of a mobile device for an industrial and potentially safety-critical domain is a major challenge. Firstly, field evaluations of an early stage prototype such as the one described here could cause a hazardous situation. Secondly, evaluating mobile systems in the field limits means of control and significantly complicates data collection (Kjeldskov and Stage 2003, Kjeldskov et al. 2004). Because of these issues, Maersk-Line did not want to evaluate the prototype on board their container vessels at this stage of the project but preferred studying the use of the prototype in the safe and controlled settings of a high-fidelity ship simulator used in their training programs. In addition to this, it was decided to complement the study of use by real users in a highly realistic simulation using a heuristic expert evaluation focusing on potential usability issues of the prototype design.

5.1. Heuristic inspection

For the expert evaluation, we applied an established method for heuristic inspection developed by Nielsen and Molich (1990). The aim of this approach was to test the basic design of an interface using few resources and without involving users.

The heuristic inspection was conducted by a team of three usability experts holding master degrees in computer science with specialization in HCI. The team was given a 15-minute introduction to the use domain covering basic maritime concepts, the operations to be supported, distribution of work, and present procedures of communication (figure 11, left and centre). They received no instructions on how to use the prototype. Aided by a standard heuristic for usability design (Dix et al. 1998), each person spent one hour checking for usability problems while using the prototype. Following the inspections, the team spent one hour producing a final list of problems.

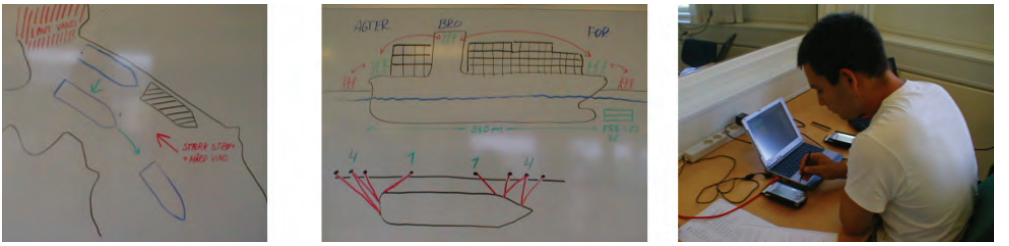

Figure 11. Heuristic inspection: instructions on whiteboards and inspection setup

Results

All three inspectors were able to use the prototype on their own and expressed that the interface design was intuitive and provided overview of ongoing activities and the status of the ship. Twenty-seven usability problems were identified. These were primarily about the graphical design and dialogue between users. Firstly, the history list was criticized for fragmented information, unclear direction of sorting and absence of timestamps. Furthermore, the expert team found the depiction of the ship and mooring lines lacking detail regarding activities (e.g. a line being heaved in). Secondly, errors occurred because the system did not prohibit some commands from being issued before the necessary preceding operations had been completed. On the other hand, further flexibility for deviating from standard commands and sequence was also found desirable. Especially options for withdrawing or correcting commands were found missing (which was, of course, interesting in the light of the discussion of that particular issue with the domain experts during the ethnographic field study). Thirdly, the inspectors were uncertain whether the users would understand compressed statements, different technical terms describing the same objects, and requirements for implicit knowledge. Finally, the difference between confirming receipt of a command and reporting the completion of the related task was found to be unclear because of linguistic similarity.

5.2. Evaluation with captains and officers in ship simulator

While the heuristic inspection provided us with input about the usability of the screen design of the prototype valuable for further refinements, the most interesting and important evaluation study was, of course, the one carried out with real users in the

ship simulator. For this study we used a state-of-the-art ship simulator facilitating a fully equipped bridge and a high-fidelity interactive scenario of the operation of a large vessel to create a highly realistic yet controllable and safe environment thus combining strengths and benefits from both in situ and in vitro studies (figure 12). This approach is similar to other prototype evaluation studies of human-computer interaction design for industrial and potential safety-critical domains carried out in full-scope training simulators (for a recent example, see Norros and Nuutinen (2005) on the use of a nuclear power plant simulator for evaluating an experimental safety information and alarm system).

Figure 12. Use in a ship simulator: the simulator and the video recording

While we could not study the use of the prototype in the real world, we went to great lengths to ensure that the evaluation in the simulated use context was as realistic as possible. This was done by firstly, by developing a highly realistic and challenging scenario for the evaluation, simulating real world phenomena from the intended use context at a high level of fidelity. The scenario was developed in collaboration with Svendborg International Maritime Academy, which produces some of the most highly educated maritime officers in Denmark, and runs the simulator facility used for the evaluation. Secondly, the test subjects recruited were high-ranking real prospective users with several years of real life experience with the operation of very large commercial vessels as either captains or leading officers.

The ship simulator consisted of two separate rooms: a simulated bridge and a nearby control room. The bridge was fully equipped with controls for thrusters, propellers, rudder, etc., as well as instruments such as dobler log, echo sounder, electronic maps, radars, VHF radio, etc. From the control room, simulator operators could see the bridge on a closed circuit video surveillance system. The computer application driving the simulation made it possible to simulate the operation of any computer-modelled vessel at any modelled physical location. Also weather and dynamic traffic conditions could be included in the scenario.

The evaluation in the ship simulator involved six test subjects, divided into three teams of two experienced captains and maritime officers, given the task of departing from harbour using the prototype system for communication between bridge and deck. The captains were on the simulator bridge and the first officer was in a neighbouring room set up to simulate the fore deck. As a part of the realistic scenario developed for the evaluation, the captain had to consider all aspects of manoeuvring the ship. This included controlling the rudder, propellers and thrusters as well as communicating with personnel on the ship, harbour traffic control, etc., and keeping clear of and taking into

consideration the movements of other vessels. The first officer on deck had to orally forward commands executed by the captain via the mobile device prototype to the operator of the simulation (acting as the team of assistants carrying out the actual tasks) and report back to the captain. The operator would then enter the commands into the simulation (making the vessel respond differently to controls on the bridge as it would in the real world), and report to the first officer when the requested operations (such as letting go a line) had been carried out. For simplicity, commands targeted at the second officer were fed directly into the simulation with feedback given by the operator. The duration of the evaluation sessions corresponded to the length of the operation if it had taken place in the real world.

The simulator was set up to imitate the operation of a large vessel in challenging weather and traffic conditions corresponding to a real world situation observed during the field studies (Nielsen 2000) merged with scenarios used for training at the Maritime Academy. During the evaluations, the captains and officers were asked to think-aloud, explaining their actions and their use of the prototype. Two evaluators located on the bridge and deck respectively observed the captains and officers and asked questions for clarification. Total views of the bridge, deck, simulator control room as well as close-up views of the mobile devices were captured by four video cameras and merged into one video signal providing a synchronized view of the whole setup (figure 12, right).

Following the evaluation sessions, a semi-structured group interview of 10-15 minutes was carried out reviewing the whole operation and discussing the use of canned communication as a supplement to spoken communication.

Data from the user-based evaluations was analyzed qualitatively and quantitatively by two researchers in collaboration producing a ranked list of usability problems as experienced by the captains and officers. Data from the interviews was analyzed qualitatively by 1) relating responses to associated usability problems and thus providing a more detailed account for them, and 2) extending the scope of the evaluation session findings (which traditionally tend to focus on problems rather than on potentials) with a set of themes related to user acceptance and ideas for extending and refining design.

Results

Observing the use of the prototype by prospective users performing a realistic operation in the simulator provided rich data on the usability of canned communication for coordinating distributed work tasks. First of all, the user-based evaluation showed that it was possible to communicate primarily by means of canned text messages while doing a real-world operation. Secondly, the captains and officers expressed that the text-based channel of communication and the graphical representation of the ship gave them advantages compared to the walkie-talkies. Generally, the captains and officers learned to operate the prototype within the completion of one to two threads of communication. The differentiation between future and present commands appeared intuitive as well as the use of parallel threads of communication and technical notions. The pictogram was highly appreciated for providing a quick overview. The desire for more detail about, for example, what people were *doing* fore and aft was expressed both during the evaluations and in the post-evaluation interviews. At the same time, however, the threaded strings

of conversations were found to be indispensable supplements to the pictogram for more details while the history list was rarely used and thus took up valuable screen space. In response to the automatic translation of commands between two languages (Danish and English), the officers and captains reported in both the evaluation and in the post-evaluation interviews that this appeared completely transparent to them.

The simulator evaluation revealed 22 usability problems experienced by more than one user. Firstly, we identified a need for correcting or withdrawing commands (again, this was interesting in the light of the findings from the ethnographic field study). Also, we identified a need for requesting or reporting something out of the ordinary. Moreover, a number of standard commands were missing, for example, dismissing a team or requesting a status report. Thus, some captains and officers used the radio to retract a command or notify that a command could not be executed. Secondly, we observed that while all captains and officers executed commands or reports straightforwardly, the procedure for confirming having received a command or report was unclear in the current design of the prototype where those possible utterances appeared in the same list as possible commands. Most of the captains and officers did not immediately notice these new confirm options in the list of commands. One officer misinterpreted it until it was explained to him. One of the captains did not confirm reports from deck until four or five had piled up. On deck, this lack of feedback caused doubt as to whether or not reports had been successfully received. Finally, some officers on deck expressed that while textual communication supported overview and persistency, having to look at the device for reading an incoming command was not always ideal. In the post interview they expressed that they would like to be prompted by, for example, a synthetic voice in combination with the option of looking at the device to get a complete overview when it suited them.

6. DISCUSSION

The two usability evaluations and discussions with prospective users and domain experts revealed several interesting results about the use of canned communication and provided substantial input for refining the prototype system. Canned communicating reduced many of the problems listed in section 2.1. For example, it was obvious that the problems of poor sound quality and lack of persistence were eliminated and that partial automation by automatically suggesting commands proved possible. Furthermore, the graphical representation of the operation successfully supported maintenance of common ground. At the same time, however, interesting new challenges of canned communication also emerged. Below, we discuss some of these challenges and present some of our ideas for improving the use of canned communication.

6.1. Limitations of canned communication

Designing a text-based mobile messaging system for canned communication turned out to be an interesting challenge. As described above, the prototype is based on a reduced version of the conversation for action model. While this model provided a valuable foundation for structure and design, our evaluations also indicated a number of shortcomings, some of which have previously been discussed in the CSCW literature

(Winograd 1994, Suchman 1994). The current design of the communicator did not support the handling of three types of non-standard situations. The first was retraction of a command. Even though our field study and interviews found this to be unnecessary, the usability evaluations showed that this was not the case and that the captain may indeed want to modify or withdraw a command that had already been issued. A full implementation of the conversation for action (which would be technically trivial) would facilitate this. The second was error prevention. The change from continuous and open radio communication to discrete and closed text-based communication seemed to increase the risk of stating a wrong command (it is easier to select a wrong item on a list than to accidentally state a wrong command verbally). The third type was unanticipated communication. In an emergency situation, communication changes from asynchronous to immediate because the situation develops quickly. In this situation, the benefits of canned communication will be overshadowed by its limitations and communicating unconstrained from pre-defined messages will be necessary.

The evaluations also indicated some risk of task interference. When auditory communication is replaced with screen-based interaction some of the user's visual attention is diverted from the task being conducted to interacting with the mobile device. The captain and officers are already watching crewmembers, instruments, mooring lines, other ships, etc. In addition, they are watching their own physical actions. While relieving the highly busy auditory channel by introducing text messaging, having to look at a screen to handle communication puts additional burden on the users' vision, which in some situations may not be appropriate. In response, officers and captains suggested combining the two in a flexible manner.

6.2. Improving canned communication

The two evaluations and the post-evaluation interviews provided massive input for improving canned communication. Some of these are simple and closely related to the specific interface design of the prototype. Firstly, the history list may be hidden in a sub-menu thus freeing up valuable screen real estate. Secondly, the graphical representation could be extended to include more detail and, for example, reflect ongoing work activities. Thirdly, in order to bring attention to pending confirmations, these should be separated from commands, for example, by displaying them in two separate lists. Other problems are more general and complex, and require the development of new ideas and further evaluations.

Modifying and withdrawing commands

The lack of facilities for handling non-standard situations was found to be a key problem. Some of this problem would be solved trivially within the present overall design by implementing the full conversation for action model (figure 4) rather than the reduced execution of a direct command model (figure 5). A facility for modifying or withdrawing an issued command could then be included by introducing a special type of command that aborts an ongoing command and sends out a counter-order. If an error occurs frequently and is handled in a standardized manner, it can be integrated in a way that is similar to retraction. Otherwise, it must be handled as a case of unanticipated communication. The whole issue of modifying an issued command naturally raises the question of what

happens if someone sends a wrong command? This can take time to correct and result in wrong actions to be taken. Essentially the need to modify or withdraw commands is not a new challenge emerging from the use of textual communication but also applies to spoken communication. Hence the use of canned communication does not introduce this challenge as such but merely inherits it. However, as canned communication based on selecting an utterance from a list rather than speaking it out may introduce a problem of commands being sent *by mistake*, a central challenge of building in the full flexibility of the communication for action model will be to produce a design that minimizes the risk of this happening, for example through a prompt for confirmation. What also needs to be considered in the design of communicator systems such as the one presented here is who has the overriding power to modify or withdraw a command? Does this privilege apply to everyone or just to the one issuing the order in the first place? In implementing the full conversation for action model, the ability to modify or withdraw a command would be distributed on all communicating actors through (potentially infinite) loops of negotiation.

Flexibility

Related to the need for modifying and withdrawing commands on a structural level, the use of canned communication also raises new challenges in relation to the flexibility of communication. Unanticipated communication, for example in emergency situations, seems to require flexibility and thus conflicts fundamentally with the motivation for using canned communication which takes advantage of the structures of standardized conversations to make it persistent, freeing up resources for other tasks. While new utterances may, of course, be "canned" in the system over time, it is very likely that new exceptions will also continue to emerge, thus eventually making the complexity handling the number of possible canned utterances outweigh the reduction of complexity gained from using them. Thus, other means of supporting flexibility should be considered.

As suggested throughout the paper, canned communication in industrial domains such as the one explored here should not be seen as a replacement of spoken communication but as a supplement. Hence one way of dealing with the flexibility issue is integrate facilities for radio communication directly in the mobile device and simply revert to this for communication out of the ordinary. In fact this was exactly what happened in the ship simulator. Combined with facilities for withdrawing a command, as discussed above, this would give the communicating partners full flexibility on top of a baseline persistent channel of communication. However, as human perception and action are to a large extent driven by expectation (Oatley, 1979), strong expectations about what channel to use in which situations is needed among the co-workers for such a multi-modal communication channel to work.

Another way of increasing the flexibility of canned communication is to look at the syntax of the individual speech-acts themselves. In the operation of letting go the lines, for example, commands typically consists of 1) *actions* (get ready, let go, etc.), 2) *objects* (spring, line, etc.) and 3) *locations* (fore, aft, etc.). Taking this differentiation into consideration, it would be possible to let the users create their own speech acts by combining a selection of actions, objects and locations rather than canning *complete* similar speech acts (such as "let go spring aft" and "let go line aft") as separate instances.

On the interface level, this could be done in a very simple manner by replacing the single menu of possible commands with three menus of possible actions, objects and locations.

Minimizing task interference

In order to reduce task interference, the use of alternative input and output devices could be considered. The requirement for visual attention towards a handheld device could be reduced by means of a wearable head-up displays or speech synthesis, and extending the device with a headset and voice recognition could support hands-free interaction while still maintaining the benefits of computerized persistent communication.

The discussion of alternative input and output media and modalities also raises an interesting question of whether all collaborating parties actually need the same representation of information, modalities and means of interaction or if differentiating between these in accordance to the context of each individual user would be preferable. Based on our findings from the evaluations, there are good reasons to explore solutions where, for example, officers on deck get commands delivered primarily through synthetic speech (allowing for the benefits of canned communication) while also having access to a secondary visual (and hence persistent) representation of the ongoing tracks of conversations in the form of text or a graphical representation of the vessel and mooring lines, or both. On the bridge, our field studies showed that during operations involving multiple physically distributed mobile collaborating actors the audio channel is the busiest one compared to the visual one. At the same time, it is the captain who has to keep track of most parallel tracks of communication. Hence the captains, not surprisingly, attached high value to the graphical representation of ongoing threads of communication and especially to the representation of the current status of the vessel. In relation to this, it would be interesting to investigate whether improving the graphical representation of the vessel could make the textual threads of utterances redundant. Also, as the bridge typically accommodates a physically co-located group of people (captain, harbour pilot, helmsmen, and sometimes machine engineers) clustered within a few meters, complementing their mobile devices with larger situated displays could provide a useful means for maintaining common ground and facilitating asynchronously "listening in" to secondary tracks of communication and thus staying "in the loop". Because the utterances are already persistent and formalized within the computer system, translating between input and output media and modalities would not be difficult to implement (see 4.1).

6.3. Canned communication in industrial domains revisited

The presented mobile device was designed and evaluated for a specific industrial domain: the operation of large container vessels. This domain is characterized by activities proceeding at regular pace leaving time for the involved actors to read and comprehend written communication. Also, established procedures exist and communication is formalized. In the case of emergencies and other non-standard events, this pattern is broken and workers should shift to spoken communication. Other industrial domains may have different characteristics. There may be more people involved, a much higher level of stress, and need for rapid concerted action. In such domains, the ephemeral nature of audio may sometimes be an advantage and actors may benefit more from sharing information by overhearing other people's communication than we observed

in the maritime domain where multiple clearly separated channels of communication were used to contain communication to specific and delimited groups of co-workers. The auditory communication also provides the listener with an impression of emotional state, identity of the speaker, and ambient noise, which may or may not be important issues to consider. These aspects illustrate that the design of a mobile communication device for one industrial domain cannot simply be transferred to another without further consideration. Comprehensive studies and analysis of the domain in question must be carried out, designs must be tailored to the unique features of this domain, and substantial evaluation studies must be carried out to validate the quality of the design and inform further refinements.

7. CONCLUSIONS

Based on a thorough ethnographic study we have explored the use of "canned communication" in an industrial and potentially safety-critical domain through the design and evaluation of a mobile prototype system. The prototype system supplements spoken communication with predefined, canned, text messages and provides a persistent graphical representation of an operation in progress and a filtered list of completed tasks. Two qualitative evaluations were conducted, a heuristic inspection and a user-based evaluation in a high-fidelity simulation of the use domain, providing rich and varied input on the potentials and limitations of canned communication for coordinating distributed and mobile work activities. Together, the two evaluations clearly indicate a series of advantages of canned text-based communication over spoken communication, but also bring attention to a number of challenges for canned communication regarding, for example, flexibility and task interference.

The mobile device was designed for a very specific and specialized domain but the concept of canned communication, as well as the central design ideas of the prototype system have value for the design of persistent mobile communication systems in general. In particular, the grouping of communication threads and the generation of a graphical representation, which integrated physical location, language, role and task proved to be highly useful. In order to increase the generality of our findings, additional studies of canned text-based communication on mobile devices should be conducted in both similar and different domains. The simulator-based usability evaluations should also be complemented with real-world evaluations over longer periods of time investigating the long-term use of canned communication. While requiring a very refined and stable prototype system, such evaluations might provide a basis for assessing other relevant factors such cognitive workload and possible reductions in time spent on communication, as well as identifying further benefits and challenges of canned communication.

ACKNOWLEDGEMENTS

The authors thank Peter Bøgh Andersen and Morten Nielsen who did the initial ethnographic studies, Svendborg International Maritime Academy and all test subjects. The evaluations were planned and carried out in collaboration with Mikael B. Skov and the heuristic evaluation was done by Rune Thaarup Høegh, Karsten Kryger Hansen and Søren Lauritsen. We also thank Steve Howard for comments on an earlier draft.

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Part II

Designing and building

Chapter 7. User- and technology centeredness

Chapter 8. Socio-physical design

Chapter 9. Sketches and mock-ups

Chapter 10. Ethnography and object-orientation

DESIGNING AND BUILDING

Part II addresses the question *how can we design and build interactive mobile systems grounded in context?* In order to make use of our empirical and theoretical understanding of context in the exploration of a design space, we need to develop ways of transferring this knowledge into the design activity, develop ways of grounding design ideation and exploration in such input, and support synthesising multitudes of ideas into concrete interactive systems. Four of my own contributions to this are included in chapters 7-10. These chapters adress and discuss possible ways of supporting the creative process of moving from abstract understanding towards concrete artefacts by using *form and context ensembles* as the central point of gravity for design exploration.

User- and technology-centeredness

Chapter 7 discusses user- and technology-centeredness. In this chapter we ground the design of mobile interactions in our experiences with processes that are either user- or technology-centred. The chapter provides a meta-commentary on the relative values and limitations of inspirationalistic and structuralistic creativity for addressing the same mobile interaction design brief as a part of the "TramMate" project in Melbourne, Australia. The chapter concludes that neither of the two approaches was superior, but that in concert they appeared to have potentials for complementing each other very well within a broader approach: the user-centred approach grounding design in the contextual complexity of current practice, and the technology-centred approach providing a counterpoint grounded in the context of future technical possibilities.

Socio-physical design

Chapter 8 explores a socio-physical approach to design. In this chapter we propose and illustrate an inter-disciplinary approach to designing mobile interactions combining rapid ethnography, architectural analysis, design sketching and paper prototyping. The socio-physical approach combines inspirationalistic and structuralistic creativity by, on one hand, informing unrestricted idea generation through inspirational and ambiguous representations of context and, on the other hand, offering a stepwise and structured process for translating the understanding of socio-physical context into specific design ideas. The approach was explored through a mobile interaction design case study following on from the empirical work presented in chapters 3 and 4 and leading to the design and implementation of an interactive mobile prototype system.

Sketches and mock-ups

Chapter 9 illustrates the use of sketches and mock-ups. In this chapter we revisit the study of intimacy from chapter 5, and describe how our understanding of personal context was used to inform mobile interaction design. The chapter discusses the use of interactive technologies to support intimacy and describes our activities of ideation and interaction design. These took place through a semi-structured process of sketching and mock-up development in collaboration with study participants, adding a level of structure and method to the design team's mainly inspirationalistic type of creativity. The diversity in scope and form of designs produced illustrate how sketches and mock-ups are a highly flexible means for exploring and communicating ideas in a heterogenous design team.

Ethnography and object-orientation

Chapter 10 explores the combination of ethnography and object-orientation. In this chapter we propose and describe an inter-disciplinary combination of methods for supporting the design and development of interactive mobile computer systems. This combines inspirationalistic and structuralistic creativity by integrating an open-ended method with a structured one. The chapter presents two case studies of mobile system development, following on from the work presented in chapter 6. The two studies show that ethnographic data is highly valuable for developing object-oriented models by providing contextual richness. In return, object-oriented analysis is a valuable way of working with ethnographic field data by providing structure. Combining the two we were able to strongly inform system design with our ethnographic field studies.

Chapter 7

User- and technology-centredness

Jesper Kjeldskov and Steve Howard

Abstract. We provide a meta-commentary on two approaches used for designing context-dependent mobile devices. On the basis of a 'user-centered' approach, consisting of interviews, observation of current practice and enactment of future scenarios in context, a number of non-functional design sketches were developed. While these sketches reflected a rich understanding of current work practices, they were little more than abstract speculations about future practice; *lacking in detail on usability and feasibility, and being largely reactive to current problem situations*. Conducted in parallel, the technology-centered study informed the design and implementation of a mature functional prototype. This facilitated a comprehensive usability evaluation revealing a series of technical challenges and problems related to mobile use. Though the technology-centered approach provided detailed input for refining the prototype, and an initial provocative break with current practice, it was less useful in supplying further original alternatives; *post-evaluation, the design discussion was largely reactive to the current prototype*. In concert, the two approaches complement each other well; the user-centered approach grounding design in current practice, in all its contextual complexity, and the technology-centered approach providing a counterpoint in technically detailed expressions of future possibilities.

1. INTRODUCTION

Mobile, pervasive and ubiquitous computing constitutes a challenge for human-computer interaction design. Like other emerging technologies, these technologies are characterized by being different from traditional desktop computers in their physical appearance and the contexts in which they are used. Consequently, they often imply interaction dissimilar from how computers are usually operated and are used for purposes beyond office and home computing. Many traditional approaches to

Originally published as Kjeldskov, J. and Howard, S. (2004) Envisioning Mobile Information Services: Combining User- and Technology-Centered Design. In *Proceedings of APCHI 2004,* Rotorua, New Zealand, LNCS (180-190). Berlin: Springer-Verlag. The epilogue was added in October 2010.

HCI design are evolutionary and based on incremental iterations of analysis, design, implementation and testing. These methods have proven valuable in relation to the development of computer systems with high usability based on well-known and widely adopted technologies such as desktop workstations and the Internet. In the light of emerging technologies, however, interaction design research has been stimulated into the development and use of design approaches that are less analytic and more creative. These approaches supplement traditional HCI methods by introducing an explicit focus on envisioning future technology and its use – so called 'blue-sky' research. The fundamental assumption is that just like the introduction of personal computing and computer networks have led to huge and unexpected changes in the work and leisure activities of many people, so will mobile, pervasive and ubiquitous computing in the decades to come. As the potential use of these technologies is, however, still unknown, researchers must develop new concepts and ideas for future technology: what it may look like, what it may be used for, and how people may interact with it.

HCI research promotes two overall approaches to concept design for emerging technologies: 1) experiments driven by the opportunities offered by new technology and 2) user-centered design driven by field studies. While a recent literature survey (Kjeldskov and Graham 2003) shows a tendency towards mobile HCI being driven by technology- rather than user-centered approaches, growing attention has lately been brought to concept development methods focusing on present and envisioned future user activities. Much of this research has its roots in the Participatory Design tradition (Greenbaum and Kyng 1991), and is motivated by the observation that "we can make amazing things, technically, but are often at a loss to understand what to make", as stated by Vygotsky (1978). In response to this, new methods are introducing techniques from theatre, such as actors, props and role-playing to HCI research. Sato and Salvador (1999) suggests a focus group approach modified to involve actors and an active audience acting-out use of existing and non-existing product concepts. The benefits from this approach are that the theatre approach creates a strong context with focus on interaction as well as an improvisational space for the participating users. However, it is also noted that it can be difficult for users to be creative and articulate on non-existing products in fictive use scenarios. Inspired by this work, Howard et al. (2002) have experimented with the use of 'endowed props' providing the design team with a means of directing the discourse between science- and plausible-fiction. Extending this line of thought, Iacucci et al. (2000) presents techniques where enacting the use of future technology is a part of a board game or takes place in the real world (the SPES technique), thus restricting discourse by means of a game master or the constraints of real life activity.

These and related techniques indicate a plausible approach to interaction design for emerging technologies. However, they are to a large extent disconnected from real technology. While on one side this frees designers from the technological constraints of the present, it also inhibits the exploration of new technological potentials and may blind insight into limitations of present and emerging technology. Hence, Rogers et al. (2002) promotes that instead of choosing between a user- and a technology-centered approach, blue-sky research should explicitly involve both playful visions of technology in their social context and innovation through 'technology inspiration'.

On the basis of this discussion, this paper presents a research project in which a user- and a technology-centered approach were combined for envisioning design of mobile information services for the same problem domain. The first section describes the motivation and methodological design of the project. Following this, the details of the user- and the technology-centered approaches are described and discussed. This includes a description of the empirical methods used, the designs produced and the evaluations conducted. Finally, the interplay between the two approaches is discussed and directions for further research are outlined.

2. SUPPORTING THE USE OF PUBLIC TRANSPORT

Between October 2002 and April 2003 we conducted a research project focusing on the potential use of context-aware mobile computing for supporting the use of public transportation in Melbourne, Australia. The project was motivated by discussions among consultants and sales staff of a large IT company about alternatives to the use of cars for traveling in city meetings with clients. In large cities where traffic is often very dense, traveling by car can be highly time-consuming, necessitating much planning. Using Melbourne's tram-based public transport would not only be more environmental, but might also be more effective if supported by a mobile information service providing travelers with relevant information at the right time and place.

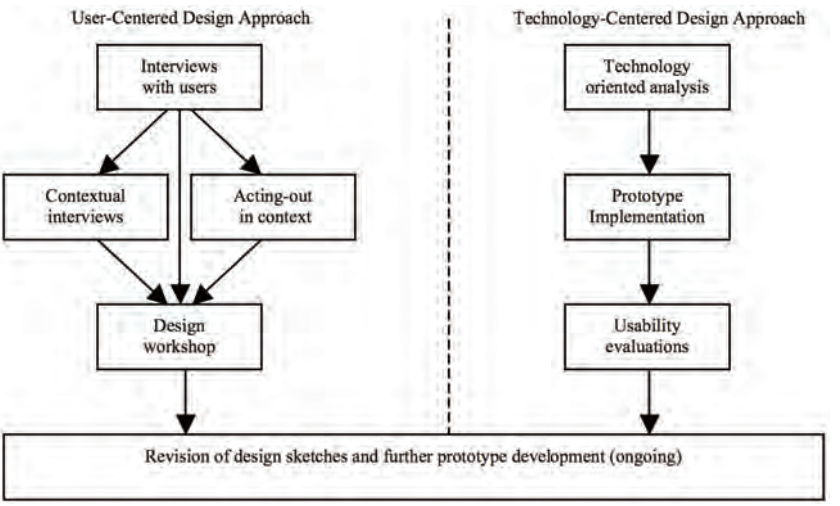

Figure. 1. Combining user- (left) and technology- (right) centered approaches to interaction design

Over the course of six months, a team consisting of three senior researchers, five Ph.D. students, two research assistants and an industrial interaction designer worked on different parts of the project. The first author of this paper managed the project and participated in the majority of activities. The researchers were all involved in HCI design for mobile computing but had different specific individual research interests ranging from ethnographic user-studies to prototype development and usability evaluation. On the basis of the different points of interest, the project consisted of two parallel tracks of research: a user- and a technology-centered track (figure 1).

The user-centered track grew out of the initiating discussions with the IT professionals. The technology-centered track grew out of an already ongoing activity to develop a mobile route-planning service for the tram system of Melbourne. The researchers in each track remained mutually unaware of each other's activities for the first 3 months of the project. Thus the user studies were conducted without any knowledge of the prototype development and the design of the first experimental prototype was not informed by the empirical user studies. Following the design workshop, researchers joined across the tracks and conducted a usability evaluation of the prototype. Finally, the outcomes from the two tracks of research were merged. The following sections describe the activities in the two parallel tracks in detail.

3. THE USER-CENTERED APPROACH

Based on the discussion above, we designed a user study to investigate into the current and possible future work practices of our nomadic users. In order to construct a rich understanding of travel and work practices, and building on project members' experience with techniques for acting-out future scenarios from previous research (Howard et al. 2002) we combined three empirical methods: 1) Semi-structured interviews with users (at the office), 2) Contextual interviews and observation of current practice (driving cars in city), and 3) Acting-out future scenarios in context (on board trams in city)

These methods all involved users talking about their perceptions, activities and needs. While the semi-structured interviews were separated from context, the contextual interviews and acting-out sessions took place while the users were carrying out real work activities. During the contextual interviews and acting-out sessions, we observed current practice, including the use of different artifacts in relation to the work activities being carried out. In the acting-out sessions we furthermore provided a series of non-functional props to assist the users' imagination. The three methods and a summary of their primary outcomes are described below.

3.1. Interviews

To establish the context, four semi-structured interviews were conducted with the IT professionals, who frequently traveled for work activities in the city. The interviews focused on the users' perceptions of pros and cons of traveling by car and tram. Each interview was conducted by a pair of researchers and lasted 30-60 minutes.

It was clear from the interviews that the users were willing to use public transport when attending meetings in the city, but that the use of the local tram system had a number of limitations. Firstly, uncertainties were related to route planning: which routes to take, when to change trams, how many changes would be needed, would there be a wait at each change, how close was the tram stop to the desired destination…? Often users would tend towards their car, or a taxi, if tram changes were needed, or if the journey was to an unfamiliar destination. Being able to predict the time of arrival of the tram rather precisely was seen as critical. The interviewees attempted to avoid being either late or too early (thus wasting time for their clients, or themselves respectively). To assist in timely arrival at appointments the interviewees needed to know exactly when to leave their office in order to arrive at their meeting just at the right time. When using

the car this estimation was reportedly done based on knowledge about normal traffic conditions in the city and was not very precise. Uncertainty about combining routes, trams not running on time, finding the nearest stop and having to walk all constituted barriers to tram use.

3.2. Contextual Interviews and Observation of Current Practice

Following the interviews, the next phase consisted of observing and enquiring into current practice (figure 2). Here we were trying to understand both hurdles and enablers to car and tram travel. The observations were conducted by shadowing the users during travel from their offices to meetings in the city. One researcher asked questions about pros and cons of using trams while another video taped the session.

From the observations we learned that, although driving to meetings in the city could be rather time consuming, the car was seen as flexible and provided a useful 'office on the move', a semi-private space for limited work activities. Thus time spent in the car was not necessarily 'wasted' time but often used for preparing the upcoming meeting or coordinating other activities over the phone.

Figure 2. Contextual interview and observation of current practice

3.3. Acting-Out in Context

The final phase of our field study consisted of a number of sessions in which our nomadic users acted-out future scenarios of using mobile information technology to support travel by tram (figure 3). The acting-out approach was adapted from previous research by project participants (Howard et al. 2002)

When acting-out a future scenario, people are asked to envision and enact situations involving future use of technology, based on an overall frame of context and supported by simple props, which are, attributed the desired functionality. For the present project, the original approach was modified in a number of ways, resembling aspects of the SPES technique (Iacucci et al. 2000). First, real users instead of actors did the acting-out. Secondly, the acting-out was done in context: using the trams for attending a real meeting in the city instead of performing fictive tasks in a studio. Two researchers facilitated the sessions and took notes; a third recorded the sessions on video.

From the acting-out sessions we learned a lot about information needs and desires and how these varied across different situations and locations. Also criteria for assessing

the appropriateness of different form factors were revealed, for example the need for privacy when working in a public space. Specifically, the acting-out in context sessions revealed that before catching a tram into the city, estimation of travel time was essential to determine when to go. On the tram, the primary information needed was when and where to get off and what to do next. In addition, users envisioned that they could prepare a meeting, browse the Internet or listen to music. One user also envisioned that the device would automatically buy an electronic ticket from the tram.

Figure 3. Acting-out in context

3.4. Design Workshop

Following the field studies, we conducted a one-day design workshop. The purpose of this was to recap and discuss the outcome of the empirical user studies and to produce a number of ideas for mobile systems supporting current and/or envisioned future practice. The workshop involved three senior researchers, three Ph.D. students, two research assistants and one industrial interaction designer. The latter managed the workshop in collaboration with the first author. First the three teams of researchers who had conducted the interviews, contextual interviews and acting-out sessions presented their findings. This was followed by a one-hour joint discussion. The participants were then divided into three groups, mixed so that they did not resemble the teams who did the user studies. The groups then spent 2½ hour on producing a design sketch of their own choice. No restriction was put on their focus, but the design had to address issues identified in the user studies. Following this, each group presented their design sketches using whiteboards and paper drawings. The workshop resulted in four design concepts. The ideas were highly creative and diverse: from a foldable mobile office to an MP3 player with voice-based route-planning, capabilities for presenting PowerPoint slides and wireless connectivity to stationary I/O devices at the customer's site. The envisioned concepts all addressed different aspects and challenges of the mobile work activities studied and were informed by both input from the interviews, the contextual interviews and the sessions of acting-out. Due to limited resources and time, only one of the concepts, described in detail below, was developed further.

3.4. TramMate

TramMate supports the use of public transportation by means of a context-aware mobile calendar application. On the basis of the field study, the basic idea of TramMate is to 1) relate traveling information directly to appointments, 2) provide route planning for the tram system based on current location 3) alert when it is time to depart, and 4) provide easy access to travel time, walking distance and number of route changes. Elaborating on ideas of context awareness (Cheverst et al. 2000) and indexicality (Kjeldskov 2002), the interface of TramMate is indexed to contextual factors such as time, location, and activity (Kjeldskov et al. 2003).

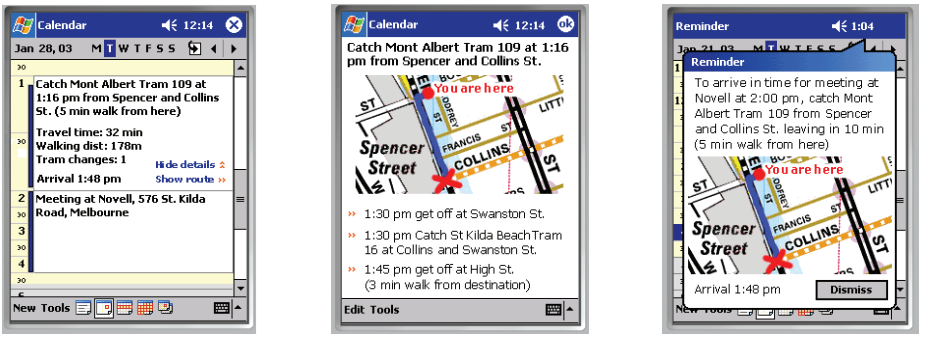

Figure 4. Refined design sketches for TramMate

The rationale behind TramMate is not to impose too much additional complexity on the user. Accomplishing this, an extended electronic calendar provides dynamic route planning information related to the user's schedule for the day. TramMate thus requires very little additional interaction. When a new appointment is made, the user is asked to specify the physical location of it, following which TramMate schedules a time slot for getting there. When an appointment is coming up, this timeslot adjusts itself in accordance with the location of the user and the estimated time needed to get there based on real time information about the public transport system (figure 4 left). Apart from specifying the first step of the route plan, the calendar view also provides additional details on the suggested route: estimated travel time, required walking distance and the number of route changes. During traveling, the TramMate timeslot continuously updates itself with information about the next leg of the route. From the calendar view, the user also has access to a screen providing his current location on a map with directions to the nearest tram stop. This screen also outlines the full route (figure 4 center). Based on the time required to walk from the user's current location to the first tram stop, TramMate notifies when it is time to leave in order to make the appointment. The reminder contains simple information about the appointment, what tram to catch, how soon it leaves, where it leaves from and how to get there (figure 4 right). On the tram, TramMate notifies when to get off and what next step to take. Arriving at the destination, a map provides the location of the appointment.

4. THE TECHNOLOGY-CENTERED APPROACH

In parallel with the user-centered approach, researchers at the University of Melbourne's Department of Geomatics conducted a technology-centered track of research with the purpose of developing a functional prototype for Melbourne's tram system. The prototype addressed the same overall use-situation involving nomadic workers in the city that motivated the user study, but was not influenced by the findings in this track of research. Instead, it was driven by a desire to explore the potentials for providing location-based route planning on GPS and GPRS enabled handheld computers.

The prototype had a number of differences from and similarities to the TramMate concept. The prototype was similar in providing route-planning facilities for the tram system based on the user's current location as a mix of textual instructions and annotated maps. However, it provided a fundamentally different user interface, requiring the user to actively look up travel information rather than relating it to planned activities, and did not alert the user before or while in transit. Also, the prototype did not automatically reflect contextual changes such as the user changing location. This was only taken into account when the user actively looked up timetable information.

4.1. Usability Evaluations

Whereas the design sketches produced in the workshop were non-functional, the prototype enabled us to study the use of real technology. We conducted two usability evaluations of the prototype: in the field and in a usability lab, involving ten subjects. The evaluations were identical in terms of tasks and the profiles of test subjects. The subjects had to complete three realistic tasks involving route planning while traveling to appointments in the city derived from the user studies with IT professionals.

Figure 5. Field evaluation

The field evaluation focused on use in realistic settings. The test subjects had to lookup necessary information on the device according to the tasks and then perform the tasks "for real" (e.g. catching a tram to a specific destination). The prototype accessed live timetable information on Internet but GPS positioning had to be simulated. One researcher encouraged thinking-aloud, one took notes and one recorded the evaluation on video (figure 5). In the laboratory evaluation, the subjects were seated at a desk, with the mobile device in their hand (figure 6). To ensure a good video recording, the subject held the device within a limited area indicated on the table. Two researchers observed through a one-way mirror and took notes.

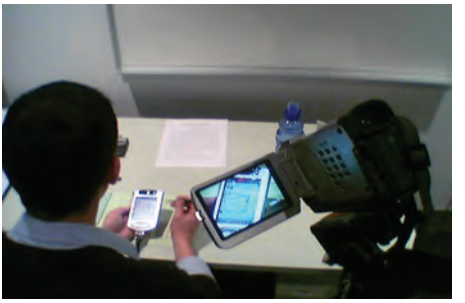

Figure 6. Laboratory evaluation

Studying the use of real technology revealed a number of problems concerning the design of context-aware mobile information services for supporting the use of the tram system. Overall, two critical and nine serious themes of usability problems were revealed (Pedell et al 2003). One of the major problems identified concerned *the relation between information in the system and in the world.* During use, the context changed constantly; the users moved, the trams moved, time went by etc. While this was to some extent reflected in the system, the granularity of this relation was not sufficient. Consequently, the information on the screen would often be often 'out of sync' with the real world. Another major problem concerned the *graphical design of maps.* All users wanted to use the maps a lot. However, the maps turned out to have three significant limitations. Firstly, the level of detail was generally not appropriate. Either the screen would be cluttered or it would provide second to no information. Secondly, the maps lacked annotation of key information such as landmarks and precise indication of the user's location, route and destination. Thirdly, the users had serious problems relating the orientation of the map to the real world and would frequently rotate the device. As a consequence, screen text was often viewed upside down.

Other problems identified included difficulties entering data while being mobile, missing vital information due to lack of visual attention, and lack of functional transparency when information on the screen changed to reflect contextual changes.

5. DISCUSSION AND CONCLUSIONS

It is interesting to compare the outcomes of the two parallel tracks of R&D. The user-centered design approach facilitated the development of design concepts representing considerable insight into present work practices, and some speculations about the future not envisioned by the prototype designers. However, the usability and feasibility of these concepts were unclear. The technology-centered approach revealed specific technical challenges and problems related to the design and use of context-aware mobile information services not considered in the user-studies. However, aside from the initial visionary prototype, the technology-centered approach largely provided input for refining the implemented design rather than informing original alternatives, thus endorsing a trial-and-error approach (Kjeldskov and Graham 2003).

With careful interleaving however, the two approaches complemented each other in the revision of design sketches and development of further prototypes by providing both

playful visions and technology inspiration based on a mix of contextual richness and technical detail. Fig. 7 illustrates this interleaving, describing design as the exploration of the relation between an understanding of current practice (acquired in this case through the interviews and contextual interviews) and speculations about future practice (expressed as the technology prototype, and explored in the evaluations).

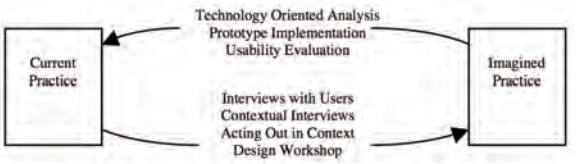

Figure 7. Interleaving user- (bottom) and technology- (top) centered interaction design

In the technology-centered approach, usability evaluation is used as a way of examining the impact, on current practice, of technology prototypes. Design proceeds by 'imposing' the design on the current situation of use during the evaluations, thereby exploring the design's impact on that use. In the user-centered approach, design moves from an understanding of current practice to imagined future use, thus driving design with user needs. Employing both a user- and technology-centred approach, results in a design process that attempts the co-evolution of an understanding of both current and future use, delivering innovative technology that is grounded in use (Howard et al. 2002b).

The technology-centered approach informed the revision of the TramMate concept by identifying those envisioned design solutions that were challenging to implement or simply not feasible. Some examples may illustrate the interplay between the approaches. The critical user need (clear from the user-centered study) of maintaining a close relation between the system and the real world was not to be satisfied by the granularity of current GPS technology (clear from the evaluations of the technical prototype); especially on trams, other means of positioning would be required. Further, studying use of real technology showed that requirements for the user to devote their full attention to the device were excessive, as envisaged in the acting-out sessions. Also, an unexpected amount of effort would have to be put into the design of the maps; including pointers to landmarks, reflecting the orientation of the user etc. Finally, additional functionality was suggested such as manual timetable lookup. The user-centered approach assisted in the revision of the prototype by indicating and prioritizing information needs, outlining realistic use scenarios and proposing a novel interaction design concept integrating the system into another application. In short, the user-studies taught us a lot about what the system should do, while the evaluations of the prototype provided valuable insight into what could be done and feedback on the usability of what a specific design solution did do.

The presented project points towards many opportunities for future research. On a system design level, the revised design concepts should be implemented and evaluated. On the methodological level, it would, among others, be interesting to enquire into the potentials of managing discourse in blue-sky research envisioning future design concepts by introducing functional prototypes into acting-out sessions.

EPILOGUE (OCTOBER 2010)

Looking back at the TramMate project now eight years later, it is interesting to reflect further on the potential interplay between technology- and user-centered approaches in the design of mobile interactions. Taking a step back and comparing the outcomes of the two approaches we were able to provide a meta-commentary on the relative weaknesses and strengths of technology- and user-centred design of interactive mobile systems. This highlighted that each of the two approaches were missing something that the other one had. In short, the user-centred approach was very useful in producing design ideas that accommodated current practice and suggested some radical new concepts. However, the real world usability and feasibility of these could not be evaluated. The technology-centred approach identified important technical constraints and challenges and produced an application that could be evaluated in realistic settings. However, the original design was far less radical, and the usability evaluation of was largely reactive to the current system. Hence, in concert, we found that the two approaches complemented each other well. The user-centred approach grounded the design in current practice, in all its contextual complexity, and resulted in novel design ideas. The technology-centred approach provided a counterpoint in technically detailed expressions of future possibilities.

Both approaches were creative processes. They were, however, different in their type of creativity. Using the terms of Shneiderman (2000), the user-centred design approach was dominated by *inspirationalist* creativity, while the technology-centred approach was dominated by *structuralist* creativity. Inspirationalist creativity is largely intuition-based in concert with preparation and incubation leading to moments of illumination. It promotes techniques such as brainstorming, free association, lateral thinking and divergence to support idea generation (Luther and Diakopoulos 2007) but would also welcome the use of scientific visualization and other ways to help understand a problem space and explore potential solutions. Although the outcome of inspirationalistic creativity is not necessarily art, much art is driven by inspirationalistic creativity. Structuralist creativity is driven by more systematic approaches and highlights the importance of methodical exploration of possible solutions by systematically breaking down the problem and structuring the solution accordingly. It promotes techniques such as flow charts, decision trees, and other structured diagrams (Shneiderman 2000), and would also include software engineering modelling such as object-oriented analysis. Although the outcome of structuralistic creativity is not necessarily science, much science is driven by structuralistic creativity.

This difference in types of creativity, and the fact that both were present and useful in the TramMate example mobile system development process emphasises an important aspect of the mobile interaction and user-experience design discipline. It is a combination of applied art and applied science and therefore also involves different types of thinking, exploring and creating. What is highlighted from the TramMate project (Jones and Marsden 2005) is that Mobile Interaction Design should combine technology- and user-centred approaches in attempts to envision future mobile systems and services. In essence what this means is that mobile interaction and user experience design requires both inspirationalistic and structuralistic creativity and is a challenge of applying art *and*

science. But how can this be done in practice? How can the strengths of the two types of creativity be combined? What does it mean to combine user- and technology-centred design? And what techniques can be used to support this?

First of all, the combination of user- and technology-centred design should probably not be done the way we did it in the TramMate project. This parallel and mutually isolated approach was only useful for identifying individual strengths and weaknesses of two approaches to a similar design problem without methodological contamination, but resulted in two designs that were difficult to merge afterwards. If done in parallel, at the very least, the two approaches should be carried out as intertwined rather than separate processes. We would like to make a slightly different proposal though. Looking at the two approaches through Buxton (2007) and Pugh's (1990) lens of design as a "funnel" of concept generation and selection that takes place over several iterations of concept generation and controlled convergence, what really happened in the TramMate project was that each of the two approaches did half of the process from ideation to refined design, but lacked the other half. The user-centred approach had a strong ideation phase but lacked technological realism and refinement. The technology-centred approach was strong in its refinement, but lacked originality in its design. Consequently the two approaches would have made a better joint result if combined *in sequence*.

This sequence of concept generation and controlled convergence from a wide range of design ideas towards detailed refinement is exactly what we believe Buxton's sketching approach offers. The central point here is that user- and technology-centred design can *both* benefit from sketching as a key technique. Sketches can capture outcomes from user-centred activities, as well as outcomes from technology-centred activities. Sketches can obviously facilitate production of a broad range of ideas informed by, for example, user studies, ethnography, etc. But sketches can *also* facilitate and capture outcomes from experimentation with technological possibilities through, for example, interactive mock-ups or smoke-and-mirrors approaches. Following this line of thought, what we labelled as a "prototype" in the TramMate project was in fact not, even though it was created in program code. It was, instead, a design representation produced to facilitate a certain type of reflection and to get a certain type of feedback. It was never meant to evolve into a real system in that exact form (or even in a slightly modified one) but was meant to be a research vehicle externalizing a design idea in order to generate feedback and new knowledge. It was a proof-of-concept implementation – or simply, an interactive sketch.

ACKNOWLEDGEMENTS

Thanks to colleagues on the TramMate project: Jennie Carroll, John Murphy, Jeni Paay and Frank Vetere (user-centered component), Connor Graham, Sonja Pedell and Jessica Davies (technology-centered approach). Thanks also go to professionals who participated in the user studies and to the usability evaluation test subjects.

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Chapter 8

Socio-physical design

Jeni Paay, Jesper Kjeldskov, Steve Howard and Bharat Dave

Abstract. As urban environments become increasingly hybridized, mixing the social, built and digital in interesting ways, designing for computing in the city presents new challenges – how do we understand such hybridization, and then respond to it as designers? Here we synthesize earlier work in human-computer interaction, sociology and architecture in order to deliberately influence the design of digital systems with an understanding of their built and social context of use. We propose, illustrate and evaluate a multi-disciplinary approach combining rapid ethnography, architectural analysis, design sketching and paper prototyping. Following the approach we are able to provide empirically grounded representations of the socio-physical context of use, in this case people socializing in urban spaces. We then use this understanding to influence the design of a context aware system to be used whilst 'out on the town'. We believe that the approach is of value more generally, particularly when achieving powerfully situated interactions is the design ambition.

1. INTRODUCTION

1.1. The Emergence of Hybrid Environments

Pervasive computing is increasingly becoming a part of our everyday lives: at work, at home, and out on the town. It is blurring the boundary between physical, social and digital layers of our inhabited spaces, providing users with highly localized contextual information. Our physical, virtual and social worlds are colliding, merging and coordinating (Rheingold 2003). We operate in the built environment using a combination of fixed devices, such as digital information screens embedded in the fabric of the environment, and hand held personal mobile devices, such as mobile phones.

Originally published as Paay, J., Kjeldskov, J., Howard S. and Dave, B. (2009) Out on the town: a socio-physical approach to the design of a context aware urban guide. *Transactions on Computer-Human Interaction,* 16(2), 7-34.

These digital devices provide both communication and computation capabilities, and therefore offer an exciting opportunity for computing to augment and enhance the way that we socialize.

Pervasive computing exploits our familiarity with the everyday environment (Dourish 2001) and breaks down the traditional mapping between activities and places, allowing people to be continually present in every place (Agre 2001). For example, cafes become corporate meeting rooms as users deal with business calls over lunch, corporate meeting rooms become social arenas while participants text loved ones unobtrusively, streets become guided walks, and plazas become information kiosks, all without any changes to the built fabric.

As our lived world becomes increasingly hybrid physical, social and digital spaces (Graham and Marvin 1996, Mitchell 1995), the intersecting issues of spatial context, sociality and pervasive digital technologies need to be understood in order to design for their inhabitant's interactions (Agre 2001). This introduces a new set of issues for analysis, including studies of the connections between physical and social space, reconsideration of existing design practices, and extension and enhancement of current HCI and CSCW methodologies (Ciolfi 2004). By understanding the influences of both the physical environment and the human activities that unfold in that context, designers will be better equipped to provide specialized computation to support likely situated interaction (Ciolfi 2004, Dourish 2001, Erickson and Kellogg 2000).

1.2. The notion of "layered" space

There are three distinct layers of space in this approach: physical, social and digital.

In the physical, architectural design has traditionally taken place within the context of an explicit set of physical and social issues in respect of anticipated activities and historical expectations of certain building types (Agre 2001, Mitchell 1995). In architecturally designed environments people make assumptions about the kinds of activities and social interactions that are supported there. This is partly determined by the physical affordances of the environment and partly determined by people's prior experiences. Physical spaces are formed to support the way that people do activities, and similarly, people's situated interactions in an architecturally designed space are shaped by cues in the physical environment about what is possible there.

In the social, our shared understanding of the physical world and the presence and activity of others helps people interpret activity and behavior (Harrison and Dourish 1996). Traditionally, the opportunities of the social layer of space have been determined by qualities of the architectural design of the physical layer. Today this configuration also includes digital elements, which by their ephemeral nature facilitate fluidity, serendipity and presence that takes us beyond the limitations of a physically built environment. In the design of hybrid spaces, architecture has acquired a new, digital, layer of expression and design extending its capabilities to facilitate and organize social interactions (McCullough 2004).

In the digital, pervasive computing is a relatively new phenomenon strongly influenced by the uptake of mobile computing technologies facilitating people's social life outside the work domain (Rheingold 2003). By extending what the built environment offers its

inhabitants, pervasive computing provides new opportunities for sociality (Jensen and Lenskjold 2004). People who are digitally connected to each other, and to the elements of the city, are now less reliant on fixed signage. They use technology to deliver relevant information 'just in time' and 'just in place', guiding them to where they want to go and what they want to do. By allowing people to make inferences about the activities of others, digital systems create environments in which new social forms can evolve (Erickson and Kellogg 2000). This digital layer not only helps structure our social interactions, but also provides a medium for facilitating and enriching everyday interactions between individuals (Erickson 1993).

In this study, the built environment is viewed as comprising these three interrelated layers: 1) the physical (material) layer comprising the architecturally designed buildings, structures, paths, signage and spaces; 2) the social layer comprising social interaction between people moving around that space, queuing, gathering, meeting etc; and 3) a digital, context aware, layer. We advocate that the digital layer should be designed based on a rich understanding of the physical and social layers of a space. Only through this will it form a direct relationship with the existing social and physical context of use.

1.3. Context Awareness

Design is about creating a 'fit' between form and context (Alexander 1964). One way of creating such a fit is to make systems context-aware, automatically adapting to the setting in which it is being used. This could be a mobile phone that automatically switches itself to silent when the user is in a meeting, or a laptop that automatically adjusts to local time. Within pervasive computing context awareness is an area of research that has received a great deal of attention. Many prototype systems have been developed and evaluated, and it has been demonstrated that value can be added to the user experience by adapting information to contextual factors such as people's location. However, a context-aware device situated in an environment should be aware, not only of its location, but also of factors like the physical and social context of that location (Agre 2001, Bell and Dourish 2004, Bradley and Dunlop 2002, Dourish 2004, Cheverst et al. 2001, Goodman and Gray 2003, McCullough 2004, Schmidt et al. 1999, Tamminen et al. 2003).

The details of what constitutes physical and social contexts of use are not well understood, at least not in a way that provides design traction. Technology rather than user studies are currently driving the development of computation and communication systems pervading our physical and social worlds (Mitchell 1999). Current software development methods and design techniques could be augmented with methods that provide detail and thoroughness in terms of understanding human experience of physical space and of the situated social interactions taking place there.

When dealing with context-awareness for mobile and pervasive computing systems, design should be based on field studies of existing situations of use, as done by, for example, Ciolfi (2004), Cheverst et al. (2000b), Paulos and Goodman (2004), and Tamminen et al. (2003). If we want a system to fit well to its physical and social context, we need to understand these contexts and their interrelationships better, and explore how such understanding can be represented in ways that are useful in informing design.

In response to this, the research presented in this paper is grounded in a human-centered empirical study of physical and social context. We demonstrate how understandings of the user's physical and social context can be achieved and represented through a structured socio-physical approach, and how such understandings can then inform interaction design. This is relevant if you are building, for example, situated display or mobile device systems with content that is indexing strongly to static and dynamic elements in users' physical surroundings including buildings and people. This could be, for example, an information system in a train station or airport, a mobile tourist guide for an historic town, or a social networking system for a new housing development.

If the factors we are going to present in this paper are not taken into consideration in the design of such systems, there is a risk of ending up with designs that, at best, do not fit well with their physical and social context of use. Worse, they may simply not get used because they get in the way of people going about their business. They could even impact people negatively by, for example, not giving them necessary information about the socio-physical character of a particular place of interest.

1.4. A Multidisciplinary Approach

Despite many projects looking at issues associated with designing context aware computing (e.g. Borntrager et al. 2003, Bradley and Dunlop 2002, Cheverst et al. 2002, Iacucci et al. 2004, Paulos and Goodman 2004, Randell and Muller 2000, Tamminen et al. 2003), only a few projects have explored the orchestrated use of information presented across multiple sources in the user's surroundings including non-digital ones, i.e. digital, physical and social information (e.g. Cheverst et al. 2000a, Kulju and Kaasinen 2002, Laakso et al. 2003, Vainio et al. 2002). To do this, we need to learn how to create relationships between the user's physical and social surroundings and the information presented digitally (Dix et al. 2000, Dourish 2004, Persson et al. 2003).

The study presented in this paper adapted and combined qualitative research methods to analyze and represent people's understanding of existing physical and social contexts in urban environments. This was then used to derive '*design ideas*' for the incorporation of physical and social context into interaction design. This approach adapted existing research methods from Architecture and Sociology to provide an understanding of physical and social contexts and representations for use in interaction design.

Architectural and urban planning methods can be used to explore the interrelationships between physical spaces and social interaction (Erickson and Kellogg 2000). Architectural research is concerned with the user's experience of the built form in the context of the activities that they are involved in. Representations of physical context can be used as theoretical apparatus to answer questions about the interdependence of technology, space and society (Hillier 1996). Hence, designers of pervasive and ubiquitous computing environments have turned to architecture and urban planning to provide a basis for devising methods for understanding physical environments. The work of architecture and urban planning involves observing how people socialize in everyday spatial environments. This has been used to draw out models and metaphors for incorporating similar combinations of physicality and sociality into digital information systems (Dieberger et al. 2000). The design of urban environments affects the degree

to which those spaces encourage social encounters between inhabitants (Ingram et al. 1996). Buildings carry social ideas within their spatial forms; in this way, spaces link to human behavior. Their configuration creates expectations about people that guide our behavior (Hillier, 1996).

Understanding the human experience of built form provides a basis for understanding the context of activities within that space and helps interaction designers to provide digital links between people's activities and their current environment.

Ethnographic methods from Sociology can be used to help developers conceptualize and reveal opportunities for pervasive computing design, and suggest system requirements (Crabtree and Rodden 2004). The study presented in this paper shows that the creation of analytical and conceptual frameworks resulting from ethnographic field studies can be used to sensitize designers to the social aspects of technology use, and support the design of relevant and appropriate technologies. In terms of conceptualizing opportunities for such design, sociological research has shown that people are constantly communicating social cues. This is so that others can perceive our social networks by the patterns of activities and the affiliations that we have (Donath 1996). As part of our social identity we have a way of aligning ourselves with particular groups (Goffman 1963). Being aware of others and the activities that they are involved in influences the choices we make about our own activities. We are also aware that the activities that we are involved in provide information to others (Erickson 2002).

By understanding how people operate socially in public places we can identify opportunities for useful digital augmentation of these spaces.

2. CASE STUDY: UNDERSTANDING PHYSICAL AND SOCIAL CONTEXT

For the purpose of understanding physical and social context, we chose a compelling urban environment, a newly opened and geographically delimited civic space in the city centre of Melbourne, Australia called Federation Square (Figure 1) (Paay 2005).

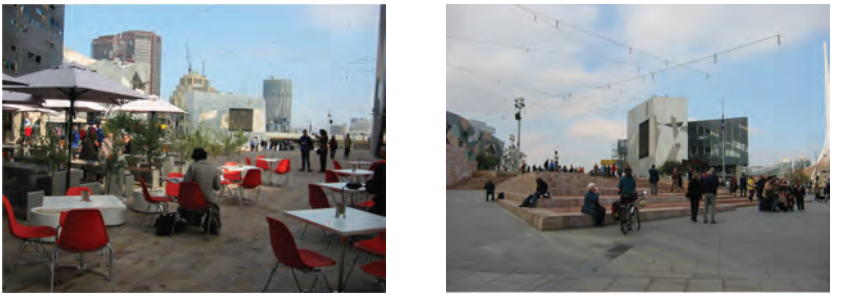


Figure 1. Images from Federation Square, Melbourne, Australia

Federation Square was chosen because it was a relatively new civic structure, opened to the public in October 2002. It covers an entire city block and provides the people of Melbourne with a creative mix of attractions and public spaces for socializing including restaurants, cafes, bars, a museum, galleries, cinemas, retail shops and several public forums. In just a few years, Federation Square has become a highly popular place to socialize for all Melbournians. It is open from early until late, every day of the week,

and it hosts a rich range of planned and ad hoc activities. Located in the centre of the city, on major tram routes, and adjacent to the main train station, Federation Square is easily accessible, is considered a landmark in itself, and is a convenient place for people to arrange to meet up in the beginning of a night out on the town. One of the design intentions for the public space of Federation Square was to incorporate digital technologies into the building fabric, creating a combination of virtual information space and physical building space for people to experience.

2.1. Investigating Physical Context

Physical context, as characterized by both Agre (2001) and McCullough (2004), consists of architectural structures and elements of the built environment that people use in every day life to orient themselves and to operate in that environment. This includes the use of landmarks as reference points, identifying legible pathways in the landscape as indication of the way to go and reading the design of doorways as places to enter. This physical context is created in response to the situated activities that occur there (Erickson 1993), and with regard for human perception of that place. For example, a landmark only becomes one in response to use as a reference point by people inhabiting that space, or a place description such as "the sitting steps" only has meaning through an understood activity that occurs there. The investigation of physicality of an environment, that is, our physical interactions with the world (Dix 2004), provides a practical understanding of physical context.

An investigation of physical context was conducted to understand the physicality of urban space as defined by the material elements of an urban environment that contribute to visitor experience of an urban space. It involved the identification of important characteristics of the physical context of an inhabited urban environment, and the creation of an analytical abstraction useful for informing interaction design. This is a somewhat novel approach in HCI to the problem of understanding context in urban space for interaction design of pervasive computing. Sociological observational studies have been made of people inhabiting urban spaces (e.g., Whyte 1980) and conceptual models have been developed to capture the nature of digital cities in urban planning (e.g., Graham and Marvin 1996). An HCI methodology developed for creating an analytical representation of people's understanding of urban environments for the purpose of interaction design could be built on these studies.

Our investigation of physical context, PIA (Physical Interaction Abstraction), resulted in visual representations representing the physicality of an urban environment including a layered map diagram. PIA combines two existing methods from the disciplines of urban planning and architecture for analysis of space: 1) an environmental image map identifying landmarks, districts, nodes, edges and paths, a representation devised by Lynch (1960); and 2) an analysis of space using the sketches and descriptions from Alexander et al.'s (1977) Pattern Language.

Lynch (1960) developed a method for visual analysis of city precincts through descriptions of key aspects of the space held by people as they navigate and orient themselves within city precincts. This was done by diagramming the interplay of visible elements in the environment that contribute to a person's environmental image of a

place. From these studies grew the categories of landmarks, districts, nodes, edges and paths as key descriptors of the image of the city held by its inhabitants. The method has proved successful at assisting in the analysis of types of elements of a city, how they are put together, and what makes for strong identity. It has also proved to be a useful technique for predicting the probable public image of that city.

Alexander et al. (1977) empirically investigated the interplay between architectural space and its inhabitants and identified architectural design problems in context and their impact on inhabitants of that environment. Drawn from observations of historical solutions to common design problems, he created a method of analyzing aspects of the built environment. This led to a collection of 253 hierarchically ordered patterns of plausible solutions making up a Pattern Language for design. Each pattern consists of photographs, sketches, descriptive explanations detailing the context for the pattern, its relationship to parent patterns, a description of the problem, the empirical background of the pattern, evidence for its validity, and the design solution.

The investigation of physical context began with an exploratory study of the physical elements of urban space at Federation Square. The analytical methods of Lynch (1960) and Alexander et al. (1977) were combined and adapted to provide a novel method for analyzing and representing qualities of physical space to provide a story about physical context of an urban environment. Lynch's method provided guidance on techniques for conducting an audit of physical elements of a space. It defines the following classification categories for those elements: district, landmark, node, path, and edge. Alexander's patterns provided a window on recurrent and complementary 'fit' between functional and spatial patterns. As Lynch and Alexander et al. both viewed their analyses of built environments from the perspective of the people who inhabit those spaces, our physical audit was undertaken from the perspective of people's perception of and interaction with the physical elements.

An observational expert audit, based on the expert audit from Lynch's (1960) method, was undertaken in single field visit to Federation Square. In Lynch's method, an architecturally trained observer maps in-situ the presence of various elements of the physical environment to create an environmental image map. In the adapted method of this investigation, the architecturally trained observer recorded through photographs and field notes the elements of the physical environment for later mapping and classification using content analysis (Neuman 2003). A total of 124 photographs recorded the material elements (building fabric, cladding, structures, surfaces, building elements, entire buildings, public spaces, paths, entrances, media screens, etc.) of Federation Square for the purpose of documenting the physical elements in the "public" areas of the space. The location, from which each shot was taken, including direction faced, was recorded on a map of Federation Square. Human activities associated with physical spaces, and the way people were using and responding to elements, were recorded in field notes. This documented every architectural element in Federation Square and its relationship to its surrounding context, including the people who inhabited the space (see Figure 2).

Figure 2. One out of the 124 photographs and notes on physical elements of Federation Square

2.2. Investigating Social Context

Social context, as characterized by Dourish (2001), includes interaction with and the influence and behavior of people in an environment. Dourish (2004) regards context as a central concept in social analyses of interaction and that social and cultural factors affect how the user makes decisions about actions and interprets a system. In understanding the social context of a place there needs to be a way to understand the social processes and human activities through studying everyday interactions. The sociality of a place reflects the social interactions that occur there and investigation of this sociality situated in an environment should provide a practical understanding of social context.

An investigation of social context of an urban space using the SOPHIA (SOcial PHysical Interaction Analysis) method was initiated to inquire into social interaction in that environment. It identified those aspects of a person's social environment that represent their understanding of social context (Paay and Kjeldskov 2008). The outcome from this investigation is a conceptual framework representing situated social context in the urban environment of Federation Square in Melbourne, complementing the understanding generated from the PIA analysis of physicality.

The PIA and SOPHIA approaches are different in the sense that the PIA map emphasizes the physical context for understanding socializing in an urban environment while the SOPHIA table provides an hierarchical representation of activities emphasizing the social context of being physically situated in an urban environment.

Our investigation developed an approach, including the SOPHIA and PIA methods, for gaining an understanding of the social context of an urban environment using rapid ethnographic methods (Millen 2000). This related social interactions to the physical environment in which they were taking place. Understanding the physical aspects of human experience of spaces can best be achieved through studying people situated in place (Ciolfi 2004). To support our approach, the work of McCullough (2001) provided insight into the situated nature of social interactions through his typology of everyday situations. This provided a framework from which to view social interactions as related to the situation in which they occur, a view in turn influenced by the physicality of the

space. McCullough (2004) draws together the concerns of architects and interaction designers by acknowledging that interaction design for pervasive computing has a direct relationship with and impact on the environment and the inhabitants of a place. As an example, digital devices can give you social information you can't see physically, such as where a crowd has gathered outside or beyond your immediate field of view.

The method of investigating social context involved observation in the built environment to identify the *social affordances* of a space. This included, for example, where people tend to go, where they tend to gather, and what they tend to do at different places etc., which contribute to the people's understanding of that space.

This method takes a grounded approach to understanding the existing social situation. It involved accompanying three groups each of three people (9 participants in all, mixed gender, young urban professionals aged between 20 and 35, and all familiar with the location), on a typical social visit to the Square. The aim was to observe and record the group interactions using McCullough's (2001) typology of 'on the town' everyday situations as a theoretical lens through which to view and guide social interactions in the field, and as a sensitizing concept in analyzing social interactions in urban environments. The categories of interest to this investigation were: eating, drinking, talking (places for socializing); gathering (places to meet); cruising (places for seeing and being seen); belonging (places for insiders); shopping (places for recreational retailing); sporting (places for embodied play); attending (places for cultural productions); and commemorating (places for ritual).

Participants were required to be familiar with Federation Square, thereby acting as key informants (Millen 2000), capturing representative interactions of an established social group. Each field visit was used to observe the social interactions of the group, the activities they participated in and how they were affected by physical space and the presence of others. Participants were instructed to go about their usual socializing practices in Federation Square. The group determined the activities undertaken and the social interactions that they engaged in. Contextual interviews from the contextual design method (Beyer and Holtzblatt 1998) were used in the field, combined with observational ethnographic methods.

Prior to each field visit the group received a 10-minute introduction to the investigation followed by a 20-minute interview about general socializing experiences as a group. This introduction occurred at a place familiar to the group, where they might meet before socializing in the city. This encouraged them to reflect on past social interactions, to relax about the visit, and gave the interviewer insight into the situated interactions that the group typically participated in. At the start of each field visit, one member of the group was taken to Federation Square and asked to contact the others to meet them there. This was designed into the method so that their meeting up processes could be observed. All groups used mobile phones for contacting their friends, as they usually would.

The contextual interviews and observations lasted approximately three hours for each visit, allowing the group to participate in many varied activities (or situated interactions) during the field visit. Reflection on past visits by participants gave additional data about their responses to alternative activities in that space, without taking the time to do them

during the visit. This reflection also gave access to the group's history of interactions in the space. The total amount of time spent in the field with the three groups was 11 hours, which proved to be a sufficient amount of time to observe that very few novel observations were occurring with the last group. The outcome from the field visits amounted to 1) approximately eight hours of digital video (Figure 3) recording situated interactions, all questions and responses, the initiation of activities and movement of the group around the square, 2) notes of ethnographic field observations, and 3) diary of reflections on visits recorded immediately after each visit.

Figure 3. Video recording the social study in Federation Square

3. REPRESENTING PHYSICAL AND SOCIAL CONTEXT

3.1. Representing Physical Context

Before content analysis of the photographs collected in the field commenced, coding of the elements of each photograph was done by assigning one or more of Lynch's (1960) five categories (landmarks, districts, nodes, edges, paths) to the focal element in each image. Using the recorded locations of the photographs, these coded elements were then used to create an environmental image map for Federation Square (see the grayed under layer of Figure 4) showing landmarks, districts, nodes, edges and paths as perceived by the architecturally trained observer.

In addition to this, one or more of Alexander's (Alexander et al. 1977) 253 patterns of the Pattern Language were associated with each photograph, which was then annotated with the pattern number and pattern title of each associated pattern. Sketches and notes showing the applicability of each pattern were appended to the existing descriptions of each image. Content analysis was then conducted on this data, involving coding it by classifying, sorting and grouping concepts in the written descriptions, and refining the themes emerging from that process. After several iterations of grouping, regrouping, forming sets of words and refining words, a concise set of representative terms emerged. These were influenced by the categories of Alexander et al. (1977) by virtue of the encoding schemas. Each of these representative terms was then related back to the original photographs, giving them the additional quality of locatability. The coding and content analysis was done by one architecturally trained researcher alone, and was

subsequently validated by a second researcher experienced with the works and methods of Lynch and Alexander.

PIA Layered Map

The visual representation that came from combining these two analyses was a layered map diagram. This showed an overview of the different Lynchian-based elements evident in the space (drawn as a grey sketched 'under layer') and the related, and specifically located, Alexandrian-based descriptions of the space (placed as a text over layer). This map, depicted in Figure 4, is specific to Federation Square but the method of creating it would be applicable to the analysis of other spaces in a similar way to derive a visual representation of an urban environment. The PIA layered map represents an abstraction of the physical characteristics of Federation Square. It provides a visual overview of the inhabited physical context of that space.

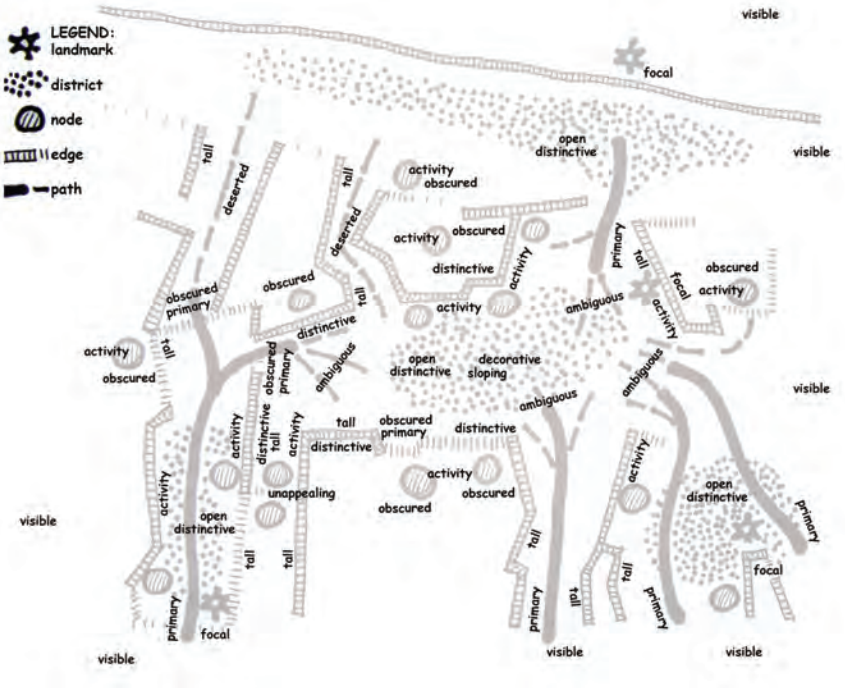


Figure 4. Layered map of Federation Square generated from the PIA approach

Surveying the layered map, it is possible to draw summary conclusions about the space, which would not be evident from viewing the original data, or from merely visiting the space. This is because it represents a composite view of that space, judiciously extracted from historical understanding of human experience of physical space through observational expert audit and analysis of urban space.

The PIA layered map provides a specific representation of those key contextual factors that characterize the environment at Federation Square (see Table 1), including the following key understandings of its physicality:

- Federation Square has: four key districts with distinctly different characteristics, each with an associated landmark.
- Federation Square has: open spaces with activity edges; distinctive and tall structures and walls; and obscured places where activities are also happening - so it is not clear from the middle of the main spaces what is around, and how to find where you want to go.
- Federation Square has: visible surrounds; some primary paths that become ambiguous when they lead into open space or are deserted or unappealing when wedged between tall walls; primary entrances that are obscured; and focal structures - so people need to use the structures and surrounds in finding their way around the space.

Table 1. Understandings from PIA related to Design Ideas

	DESIGN IDEA:	1. Location by District	2. Augmented Photos	3. Rich Descriptions	4. Use of History	5. Wayfinding	6. People and Activities	7. Meeting and Waiting
UNDERSTANDING: PIA								
Landmarks:	structures-focal	●						
Districts:	spaces-distinctive	●						
	spaces-open		●					
	surrounds-visible			●				
	ground-sloping							
	ground-decorative							
Nodes:	structures-distinctive			●				
	structures-tall			●				
	places-activity						●	
	places-obscured		●					
Edges:	edges-activity		●	●				
	entrances-obscured		●					
	entrances-primary		●					
	walls-distinctive			●				
	walls-tall			●				
Paths:	paths-primary					●		
	paths-ambiguous			●		●		
	paths-unappealing							
	paths-deserted							

PIA's significance lies in its ability to capture, in a readily accessible form, inhabited physical context. It makes available a visual representation describing inhabited space that can be used for identifying the key physical characteristics of any built environment.

This is done grounded in human observation of that place and formed with reference to collected knowledge about human understanding of architectural form.

The PIA approach is novel, in so far as it is a combination of two well respected architectural schools of thought that have both been applied in HCI before, but not in combination, and not with such adherence to their architectural origins.

3.2. Representing Social Context

The eight hours of the digital video collected during the investigation of social context at Federation Square resulted in a 60-page transcription of situated interactions 'out on the town'. General conversations about participant's families and work issues were not transcribed and were regarded as being outside the bounds of this investigation. The analysis of the transcript involved open and axial coding from the grounded theory methodology (Neuman 2003, Strauss and Corbin 1990) and the affinity diagramming method from the contextual design methodology (Beyer and Holtzblatt 1998).

Open coding is that part of the analysis concerned with identifying, naming, categorizing and describing phenomena found in the text by assigning codes to them. This involved underlining key words and repeating phrases in the transcript, identifying the phenomenon that participants described, and coding that as a category-property-dimension triplet. For example, a conversation about how a group chose to meet up resulted in the code: "MEET PLACE – choice – familiar to all". These codes were then entered into a table, recording when in the transcript this phenomenon occurred, and a longer description of it, supporting the meaning behind the code. During this process, codes were modified and merged as related and similar situations were found in the remainder of the transcript. After coding of the transcripts, category names were consolidated and refined using McCullough's situated interactions as a theoretical lens. This resulted in 214 distinct codes, grouped under the following 17 descriptive categories: Contacting, Meeting, Approaching, Entering, Eating, Drinking, Sitting, Watching, Being Seen, Attending, Viewing, Shopping, Deciding, Directing, Walking, Exploring and Locating. In the previous example, the code became: "MEETING – place – familiar", and was grouped with many other phenomenon related to people meeting up when socializing.

Axial coding is the part of the process that relates codes to each other using a combination of inductive and deductive thinking. To achieve a higher level of abstraction with our data, axial coding was used to draw a set of overarching themes from the outcomes of the open coding process. For inter-coder reliability, two researchers reviewed the codes in respect to the underlined transcript to identify overarching themes emerging from the data. The two sets of themes produced were then merged and consolidated as a joint activity to produce a group of 21 agreed themes as the outcome of the fieldwork. These themes formed the starting point for the process of further abstraction, using affinity diagramming (Beyer and Holtzblatt 1998).

Affinity diagramming drew successively higher levels of abstraction from the data through a process of grouping and sorting the 21 themes until a set of three high-level key aspects emerged. These represented the essence of the data and encompassed all lower level themes as concepts supporting these key aspects. This resulted in a

conceptual framework encapsulating a structured understanding of the context of every day social interaction providing a rich story of sociality in urban environments showing how people experience physical space and how they interact with each other while socializing in these spaces.

SOPHIA Conceptual Framework

The conceptual framework generated through the SOPHIA approach, provides a hierarchical summary of key social characteristics affecting social interaction in urban space. It consists of three key aspects of social interaction in urban environments: knowledge, situation and intention. These key aspects and their related concepts tell the following story about situated social interaction.

Prior Experience and Expectations: When interacting in urban space people draw on their knowledge in the world. They recognize entrances, and they see large open spaces as places for people to gather. They use landmarks as reference points. People operate in public places using a set of social affordances. They look to what others are doing as cues for what to do in a place. Following crowds or people queuing is a way to decide where they might go. Places where others are sitting make them feel they can sit there too. People draw on their history with a specific urban environment. Physical familiarity with a space means that they approach familiar places using familiar paths, that is, the way that they "*usually come*". They use past social experience of places as a basis for selecting places to socialize with friends this time, for example "*let's eat where we ate last time*", or require trusted recommendations to try a new place. Often they will have a personal preference for why they choose a particular place. People relate activities with establishments, that is, a place for drinking, based on their past experiences with it. If it is a place where they "usually sit outside" then it becomes the place to go in fine weather. If they are socializing with a particular group of friends they like to start the social outing in a place that they share a common experience of and often arrange to meet in the place where they "*usually meet*".

Situations, places and spaces: Situation is an important aspect of sociality in urban space. When socializing the presence of other people influences the way that people behave and move through urban space. Friends show they are a "group" by maintaining close physically proximity, e.g., walking abreast, as they move through a public place. People like to be near others but not necessarily interacting directly with them. For example, they like to share a table with others in a bar, yet not talk with them; they are "*socializing by proximity*". People like to watch others, especially if they feel unobserved themselves. The length of time that someone has to wait for a friend influences the choice of meeting place. The setting in which a particular activity takes place matters. The presence of others and the types of people in a place influences its acceptability. Generally, people like to socialize in places with similar types of people, i.e., age, dress, intentions. Whether a place is sunny, sheltered, etc., influences the choice of location to socialize or wait. The convenience and location of a place is also important. People prefer a place to eat that is near other places to eat. Surroundings are an important part of people's situation and are often used as reference points. They index to things around them, including buildings, e.g. "*the railway station*", or distinctive elements, e.g. "*that big white umbrella*". They describe a location of an unknown place to a friend by referring

to the places and activities of shared experience that they hold with that person. People describe a location as "*next to the place we went where we sat under those heat lamps*". They might also refer to a place in terms of a past event there, i.e. "*where we saw the world cup*".

Sensing-making: Sense-making is an important part of socializing in a place. People try to size up the situation. They like to get an overview of their environment. They strive to make sense of things and places around them. People make sense of what is happening in a place by assessing the activities of others. Before entering a place they tend to stand on the outside and familiarize themselves with the situation before committing to enter or join in. People gather information in an urban environment while socializing, and require differing levels of information for different activities. They view information/media screens as decoration, and if they have a query, they are most likely to ask a friend. They don't like to interact in places where they are unsure of how things operate. They want to know what is new and if there is something special happening in a place, especially their familiar places. Movement through an environment is part of their social activity. People explore places just for the fun of it, often wandering and browsing without a specific goal exploring both physical space through movement and shared knowledge through conversation. At other times they are trying to find their way to a specific place, involving transition through spaces preferring paths that have people and activities of interest along the way. Places are dynamic, and familiar and preferred paths are sometimes blocked or altered by the presence of ad-hoc structures or large crowds. People can get lost when taking an unknown route and get frustrated when signage is not helpful. In this situation, they look ahead for familiar objects. Friends spend time negotiating on places to go, and will make decisions by discussing options until they reach consensus, or someone leading the group.

This outcome of the SOPHIA analysis of social context, represented as a conceptual framework, provides a hierarchical representation of the social layer of an urban environment, and can be seen in Table 2.

This conceptual framework represents social influences at work at Federation Square, including the following key understandings of situated social context:

- At Federation Square: people's past experience with places and people (familiar places and shared experiences) and the situation of these experiences are important in choosing places and activities to socialize;
- At Federation Square: people give directions by referring to shared experiences and visible elements, and use their history and physical familiarity with a place to find their way around using familiar paths;
- At Federation Square: people like getting an overview of what is happening and want to know about the presence of other people in places and what they are doing; and
- At Federation Square people typically coordinate meeting up with friends in an ad-hoc manner, depending on activity and shared history with those friends.

Table 2: Understandings from SOPHIA related to Design Ideas

		DESIGN IDEA:	1. Location by District	2. Augmented Photos	3. Rich Descriptions	4. Use of History	5. Wayfinding	6. People and Activities	7. Meeting and Waiting
UNDERSTANDING: SOPHIA									
Knowledge: in-the-world	physical affordances	places to enter	●						
		places for gathering							
		landmarks as focal points	●						
	social affordances	cues for what to do						●	
		cues for where to go						●	
Knowledge: history	physical familiarity	familiar paths			●		●		
		familiar places				●	●		●
	social experience	past experience				●	●		●
		shared experience				●			●
		recommendations from others				●			
		personal preferences							
Situation: people	us and them	interaction by maintaining group							●
		interaction by proximity						●	
		interaction by watching						●	
		discomfort of waiting						●	●
Situation: setting	setting matters	others (social)				●			
		environment (physical)				●			
		convenience to current location				●		●	
Situation: surroundings	indexing to surroundings	index to shared knowledge				●			
		index to visible elements		●					
		index to events							●
		index to physical objects		●					
Intention: sense-making	sizing up the situation	getting an overview						●	
		pausing before committing						●	
		making sense of a place						●	
		making sense of what's happening						●	
	gathering information	different levels of information		●					
		media screens as decoration							
		what's new		●					
		uncertainty (lack of info)		●					
Intention: movement	exploring	exploration for the sake of it						●	
		wandering and browsing							
	wayfinding	transition through spaces					●		
		dynamics of a place					●	●	
		getting lost (unclear signage)					●		

Some of the observations described above were surprising to us. For instance, we were surprised about the observed influence of familiar places and paths on peoples' socializing and navigational behavior. People would rather revisit well-known places than exploring new ones, and would knowingly prefer the long way between two places to a newly found shorter path. Related to this, we were also surprised about the importance of peoples' history of socializing in Federation Square and how past and present interactions were not perceived as a random set of disjointed events, but rather as interwoven parts of a continuous experience over time. In terms of the way people communicated about places outside their immediate view, we were surprised with the extent of references made to activities and earlier interactions there, rather than to its physical properties. As a final example, we were surprised about the huge importance of social affordances of places when venturing into unfamiliar areas.

Many of the findings presented above involve, and relate, social and physical aspects of context. It is our belief that these findings would not have been noticed as strongly without SOPHIA. The SOPHIA approach can be used to analyze any urban environment and provide an analytical representation of that urban space in respect to those elements of situated social contexts that are most strongly represented there. It makes available a set of concepts representing sociality in urban space that can be used to identify key social characteristics of any built environment. It describes the user's social situation in a way that is grounded in human observation of people socially interacting in place, collected through ethnographic study of situated social interaction.

SOPHIA is unique, in so far as it represents a grounded approach to providing a widely sought representation of social context in urban environments.

4. INFORMING INTERACTION DESIGN

Using the PIA and SOPHIA methods and resulting representations of the physical and social layers of an urban environment, a pervasive computing prototype was designed for the intangible goal of 'enriching people's experience of Federation Square'.

The design process used in this study involved identification of a method, where no generally accepted one exists (Ciolfi and Bannon 2003), for taking knowledge gained during a grounded analysis of context of a space through to the specification of design requirements for a prototype system. The process of transition from field data to prototype design is a difficult one (Cheverst et al. 2005, Ciolfi and Bannon 2003, Kuutti 1996). The study presented here used a method of drawing design ideas from the PIA layered map and SOPHIA conceptual framework using a technique of design sketching (Buxton 2007) to make this link between the analysis and design processes. Two researchers reflected on these field investigation outcomes and used design sketching to extract design ideas from them. This method is a combination of idea sketching as used in, for example, architectural design (Yee 1997), interaction design (Buxton 2007, Sharp et al. 2007), and software design (Checkland 1981), and empirically grounded identification of considerations relevant for design (Ciolfi and Bannon 2003).

During the design process, the PIA layered map and SOPHIA conceptual framework were continually revisited and used to inspire seven design ideas. Using the design

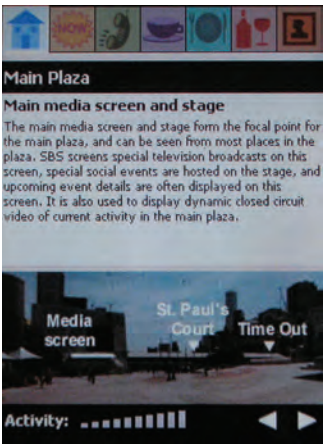
processes of storyboarding and paper prototyping, these design ideas evolved into the design ideas that guided the creative design of an operational prototype. This prototype was then used to verify the ability of conceptual frameworks to inform the design process and also to evaluate the usefulness and understandability of references to the user's current context in the human computer interface. The following seven design ideas identify key aspects of the understandings of inhabited physical context and situated social context of the urban environment studied:

1. *Location by District*: The system responds to the users' location in terms of one of the defined districts from the PIA layered map. Importantly the understanding of location is imbued with social meaning. The information provided by the system is tailored to information needs within that specific district. To help the user relate the information in the interface to their physical surroundings, the initial screen displays the corresponding landmark for that district, using physical indexicality to align the system with the real world.
2. *Augmented Photorealistic Depictions*: Each district is represented in the system by an interactive photorealistic depiction of the physical surroundings of the user augmented with textual or symbolic information needed to better understand the place. The outcomes from PIA tell us that the space has activity edges but primary entrances and destinations that are obscured. The interaction design matches the user's experience of this physical space and facilitates aligning the information presented in the system with their physical surroundings. The augmentation of these images helps people to know what is located behind the visible facades, and to identify primary entrances serving several different places.
3. *Rich Descriptions for Navigation*: Locations and instructions for navigation are expressed through rich descriptions derived from the distinctive characteristics of the place. Based on knowledge generated from PIA that activities are located on the edges, it follows that selected locations could be described as being "next to" or "opposite" other locations. These terms are used in the rich descriptions, thereby referring to locations relative to one another. The navigation information also indicates the path that the user should take to get to a place. The outcomes from PIA show that paths in many areas of Federation Square are ambiguous and not clearly indicated, but the space has visible surrounds. It therefore follows that descriptions, such as "away from the train station" or "towards the river", can be used to refer to visible elements of the surrounding city.
4. *Use of History*: The system keeps a record of the user's history of visits to Federation Square and visits of accompanying friends and uses this to deliver socially appropriate information about things to do and places to go. From SOPHIA we know that people use their history with a place and shared experiences with others when socializing. The past visits to places that they share with particular friends affect where they choose to socialize. Also, the current situation in a place, including environmental conditions and the presence and activity of others affects choices of where to go and what to do. The system makes use of the social experiences and history of the user to give recommendations to them based on this database of past visits.

5. *Wayfinding*: The system supports wayfinding using people's familiar paths and indexing to their familiar places. The outcomes from SOPHIA shows that familiar places and familiar paths are important to people. Also that if signage in a place is inadequate people get lost going to new places. A system that knows a person's familiar places can present a series of them, along with key landmarks and distinctive building features as identified through PIA, to guide a person to an unknown destination. The person will use familiar paths to get to each point thereby reducing the need for detailed step-by-step movement directions. This uses people's social experience and history with a place.
6. *Representation of People and Activities*: The activity and location of others in Federation Square is represented to the user so that they can make activity choices based on assumptions that they make about this information. Representation of what is happening, including both people and activities, helps people in making sense of a space. The outcomes from SOPHIA show that interaction between the group and others by proximity and by watching is important when socializing. There is a desire to know where other people are gathered. People are drawn to new places by the presence of others, or explore where others are out of interest. This lets users "see" important aspects of the current social context of a place that they would be otherwise unable to access from their current location.
7. *Meeting and Waiting*: The process of ad-hoc meeting up with friends is streamlined through the use of familiar places, identified groups of friends and their proximity, and information about how long a person will need to wait. This requires knowledge of the history and shared social experiences of friends. As indicated by the outcomes from SOPHIA, people coordinate meetings based on places familiar to the group, how long they will take to meet up, and what activity the group want to do. This indexes to past social interactions of a group of friends.

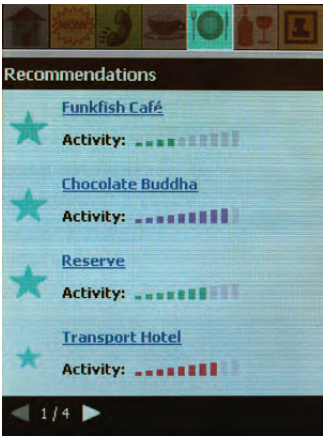
These design ideas were directly derived from the understandings generated through the PIA and SOPHIA methods, and can be directly traced to the outcomes from PIA and SOPHIA that inspired them as shown in Tables 1 and 2.

Informed by the seven design ideas, and with respect to the established functionality typically provided by, for example, mobile guides systems, a pervasive computer system prototype was developed for access through mobile devices (Figure 5).

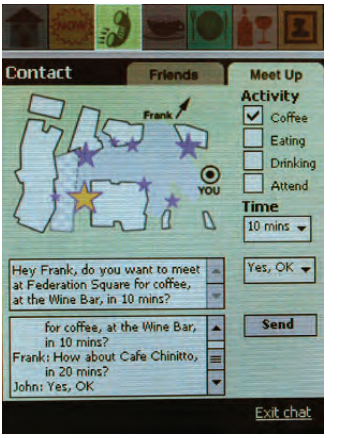


"Home" screen

"Now" screen



"Recommendations" screen



"Contact" screen

Figure 5. The "Just-for-Us" prototype system - four example screens.

The "Just-for-Us" prototype was created as a proof of concept, to evaluate the usefulness of the design ideas emerging from PIA and SOPHIA in situ. The four example screens shown in figure 5 have design elements that can be directly linked to the design ideas detailed above. For example, the *NOW* screen was inspired by design idea 6, *Representation of People and Activities,* where the location and activities of other people within proximity are visually represented on a dynamically updated map. This represents the current situation, allowing people to make sense of a place through the social affordances provided by the presence of other people.

When a user enters one of the square's four districts, the system pushes data about that district, including a panoramic photograph, to the mobile device (the Home screen). Clicking on an annotation brings up a brief description of the item. By clicking on the arrow icons at the bottom of the screen the user can rotate the view and learn about

other locations in the area. When the user enters a new district the corresponding panoramic photograph is automatically pushed to the device.

Clicking on the Now icon at the top of the home screen brings up a small map showing the user's approximate location and dynamically updated colored circles. The radius of each circle indicates the number of people present, while the color represents their prevalent activity - for example, having coffee, eating, having drinks, or attending a cultural event. Clicking on a circle calls up detailed descriptions and images of the place, for example, a particular restaurant, along with information such as way-finding directions and menus.

Just-for-Us was implemented as a server-side web application that can be accessed through a mobile web browser. For the first prototype, we used a series of HP iPAQ h5550's connected to the Internet through WLAN or a GPRS connection. The content of Just-for-Us is generated from a mySQL database containing information about the physical layout of Federation Square (derived from the architectural field study). It also holds descriptions and photographs of landmarks and transition points, and information about the different establishments and businesses in the precinct. Additionally, the database is continuously updated with information about people's current context (location, activity, social group, etc.) and keeps a history of their interactions in Federation Square. PHP is used to generate web pages on the basis of the information in the database, and JavaScript is used for handling client-side interaction and information push. Supporting the web application, a number of server-side programs perform specific sub-tasks such as pushing information to the user when appropriate and dynamically generating maps and annotated photographs. The system scans for other Bluetooth-enabled mobile devices to identify nearby friends, and uses Bluetooth beacons in the built environment for positioning. Hence, it does not know peoples' exact geographical coordinates but only their approximated location, for example if they are in a specific café or in the main square. The location of people appears anonymous. For full details of the prototype design and implementation of Just-for-Us see Kjeldskov and Paay (2005).

5. EVALUATING JUST-FOR-US

To investigate the usefulness and understandability of the prototype system, and to extend our understanding of physical and social context in urban environments, an empirical user-based evaluation was conducted. Unlike many other mobile information systems, the proposed design is built on insights into user perceptions of the built environment gained from empirical fieldwork. This facilitate presentation of information in the interface that refers to elements of the user's physical and social contexts.

The evaluations of the Just-for-Us prototype involved 20 participant pairs of mixed gender, with a history of socializing in Federation Square. Ten evaluations took place in the field at Federation Square, and ten in a laboratory. Using a mixture of field and laboratory evaluations made it possible for us to powerfully introduce the situation of use into the assessment (in the field) whilst allowing for a degree of control (in the laboratory); in doing so we asked questions of use in the field, and questions of usability in the laboratory, integrating our insights as we went. As previous research has stressed

the value of researcher control in field evaluations (Kjeldskov et al. 2004), users were given a number of overall tasks to prompt use of specific parts of the system that related to the users physical context and social context, in respect to the six design ideas that were implemented in the operational prototype. A set of tasks and field questions were devised to ensure that these parts of the system were evaluated. Supporting this approach, users were asked to validate the relevance and realism of these tasks in relation to the activity of socializing out on the town. Before taking part in a visit, each participant pair jointly completed a history survey of their previous visits to Federation Square to simulate history data that the real system would have collected automatically. For the purpose of the field evaluation, the user's position, people and friends in vicinity etc. were "Wizard of Oz'ed" (Dahlbäck et al. 1993, Buxton 2007) with data being entered manually behind the scenes without the knowledge of the test subjects.

The investigation was an evaluation of use but borrowing techniques from traditional usability studies such as specific tasks, think aloud protocol, and the data collection methods of video and audio recording. Inspired by the co-discovery testing approach to thinking-aloud studies with more than one user (Snyder 2003), pairs were asked to discuss their perception of and interaction with the system with each other. The researcher read the tasks and asked questions about participant's interactions for clarification. Each evaluation took approximately 1.5 hours. The evaluation was documented on digital video both in the laboratory and in the field.

Due to the fact that this was not a theory building exercise but an exploration of the use of the PIA and SOPHIA understandings in the design of Just-for-Us, a detailed grounded analysis of this data was deemed unnecessary. Instead the rapid ethnography method of collaborative data analysis (Millen 2000) with two researchers provided the level of feedback sought from the use evaluations. The collaborative data analysis approach was combined with the analytical technique of identifying critical incidents to produce a list of observations (Sharp et al. 2007) with each observation associated with one of the five major tasks.

The outcome of this analysis was a list of 74 issues related to user experience and comprehension of the system, for example "People want to use the map representation overview to make activity choices". These issues were then associated with specific outcome elements of the PIA and SOPHIA tables to extend the understanding represented by these frameworks.

In terms of inter-coder reliability, a total of 1390 instances of the 74 issues were coded across the 20 participant pairs. Out of these, the two researchers independently identified and coded 1318 matching instances of these issues, which shows a high level of reliability (94.9%).

6. FINDINGS

The user study provided rich data on the use of a public pervasive information system within an urban context. On a general level, the study showed that people could easily operate the system; find what they were looking for and understand the presented information and functionality. They found the design of the system attractive, streamlined

and professional looking, and trusted its content to be true. On a more specific level, most users reported that providing a public digital layer of information augmenting the city on their mobile device was “very cool”, “useful” and “fun”. In particular, people were fascinated that the system knew their current physical location, who they were with, and where other people in the civic space were currently gathering. They were also fascinated by the ability to access information about the places around them from both businesses and from other people, and they perceived the service as a credible source of information augmenting their surroundings.

The user study also provided us with the following detailed findings that can be tied to specific themes captured in the understandings generated through PIA and SOPHIA. Informed by the empirical findings of the evaluation, we can confirm that *landmarks*, that is, features that are distinct from their environment, worked well as anchor points for matching information in the system with information in the real world. Landmarks are an important focal point for people operating in urban environments.

Even though the accuracy of the system’s positioning was limited to only knowing what district or place a user was at, rather than knowing their precise geographical coordinates, this proved to be specific enough and matched with people’s perception of their current location. Within each district it was quite natural for people to use the visible surroundings for aligning the system with the real world by matching the outline of buildings and distant skylines with images on the screen. In situating themselves people would use distinctive elements and structures to make quick confirmations that they were in the right place using images on their screen to index to their surroundings. We were surprised that while doing this many users stated that they did not need such a detailed image and would be capable of using, would even prefer, a line drawing or an outline with a few detailed features. In doing this matching however, it did surprise us that even though people seemed perfectly capable of identifying and matching on a more abstract level than we had designed for, they wanted the virtual world to automatically correspond and align with their exact orientation in the real world - they expected the system to “know which way I’m facing” and would even relocate themselves a few meters to one side so that this alignment was achieved.

We found that people did treat the space as a series of interconnected *nodes*, that is, places of activity and interest, which they were keen to know more about. Given the distinctive structures of places, we found that using a physical quality of a place as a descriptor in instructions worked very well, for example, telling users to “walk toward the black building” negated the need for detailed distance and vector-based wayfinding instructions. Surprisingly the same success was not achieved using activity as a descriptor, for example, “walk past the sitting steps”. Although all participants said they were well aware which steps we meant, they were worried that activity was transient, and not necessarily happening at all times of the day.

Generally people navigated and oriented themselves using the perceived *edges* of the space. Although we understood people to use physical affordances to determine places to enter, we also knew that the space had primary entrances that were often obscured. We found these transition points were vital to people finding their way in the space,

and that augmenting an image of the activity edges of the space with text indicating the location of entrances and places supported improved wayfinding in the space.

As noted in the analysis, *paths* in the space were both very large and generally lead into the square and were not clearly indicated inside the space. This did not prove to be something that needed to be augmented by the system because as expected, people used their familiar paths, and therefore only needed fragmented detail to get to the vicinity of a new place, with more specific detail when up close.

In terms of *prior experience* used when socializing with the system, it was confirmed that people do navigate very successfully using physical familiarity. They adapt to fragmented wayfinding descriptions finding their own path as far as possible by navigating to places that the system knows are familiar to the user. However in giving these instructions we found that user's often did not know the formal name for their familiar places, and in this case resorted to viewing and recognizing a picture of their destination. In our evaluation we confirmed that it made sense to people to know about the activity and number of people at places nearby, and influenced their decision to go there. The system provided the kinds of cues, or social affordances needed for deciding what to do and where to go, but for places beyond the users current visual range. Many parts of the system relied on knowledge of the user's past social experience with the space to give directions and recommendations on places to go. Although this was successful in most cases, and people do generally favor returning to familiar places, we found that frequency of visits to a place is not a universal indicator that people want to go there this time. The system would give recommendations based on familiarity and current social situation, and it would surprise users when the system adapted to their history – most users expressed uncertainty about how to control this ability and a desire to do so. In our design we had overlooked that fact that when places are being recommended by a system, people want to know the factors influencing that recommendation. We did however have it confirmed that people regard the favorite place of a friend as a form of recommendation.

The *situation* for socializing was also confirmed as important. Knowing about the activity of people in a place influenced the decision to go there. It was interesting to note that for some individuals a busy area made them want to go there and "check it out", showing an interest in interacting by proximity, with users stating that the presence of others is a sign that a place is good. For others large numbers of people clearly indicated a place to be avoided, although some clarified this choice by telling us that it depended on the mood they were in. It was our understanding from the social study that spatial convenience was also important, but in the evaluation users said that this did not matter – this may have simply been a factor of the small-scale testing space.

People's *sense-making* when socializing was the most difficult to confirm. It was evident in our use study that people do spend a significant amount of their socializing time on making sense of their surroundings and sizing up the situation. People really loved getting an overview of other people and their activities in their surrounding environment. They appreciated having information presented to them about events that were about to happen at places around them – suiting the serendipitous form of socializing that most users engaged in. People also really liked it when the system automatically gave them

relevant information about the activity they were about to do at a place. For example, having menu information pushed to their device when in proximity of a café gave them the opportunity to pause before committing to the place, which was perceived less of a commitment than going inside to read their menu. However, what we did not foresee was that at this point users wanted to make a quick comparison between this place and others nearby without moving. Nor did we predict the level of detail that they required, including: food type, price, genre, ambience, outdoor spaces, and type of people there. Generally, we found that people exploring and making sense of an urban space wanted to be able to access differing levels of informational detail, in sequences that was difficult to predict, constantly changing, and not simply related to their current location. When delivering specific information adapted to their locational context we found that people still wanted to be able to access non-context specific information relatively easily. We also found that people required quite different information about their favorite places, such as "what is new since the last time I was there", but more general information about new places. In the wayfinding sections of the system we found that the dynamic nature of urban spaces presented a problem when using detailed photographs for matching between virtual and real world. The presence of new or temporary structures changed the look of the physical environment (and the social interactions that occurred there) to such an extent that people found it difficult to make the match. Perhaps the more abstract line-drawing-type representation, that users suggested would be acceptable, could help alleviate this problem.

7. DISCUSSION: THE VALUE OF A MULTI-DISCIPLINARY APPROACH

7.1. Understanding the socio-physical context of urban environments

One of the guiding questions of the study presented in this paper was how we could understand and represent the socio-physical context of urban environments. In response to this question, we have proposed a multi-disciplinary approach combining empirical and analytical methods and techniques from the fields of human-computer interaction, sociology and architecture. The result is a rich understanding of the social and physical properties of an inhabited urban environment, and the interplay between the two.

It is extremely difficult to separate the physical context of a space from the people inhabiting that environment. Physical context is more complex than a mere catalogue of physical elements in a specific environment, and in analyzing a built environment it is important to regard responses of the inhabitants of that space to the physical elements around them. Likewise, social context in urban spaces is more than just the existence of people and their immediate interactions with each other. Interactions occur in place and are influenced by the configuration of physical spaces. The situation of these interactions, the history of interactions in that place and experience of similar situations all influence people's understanding of social as well as physical affordances of a space. The dynamics of an interaction are very much influenced by the configuration and population of the urban environment in which they are taking place. This interrelationship between physical and social aspects of an environment is an important part of the understanding of socio-physical context of urban environments we have presented in this paper.

In informing our understanding of the socio-physical context of Federation Square, the investigation of both physical and social context produced holistic representations of the interrelationship between physical and social aspects of an urban environment. By making one part of the investigation focus primarily on the physical context of socializing in an urban environment, represented as a map, and the other part primarily on the social context of being physical situated there, represented as a table of activities, the overall investigation of the urban environment of Federation Square captures not only the unique properties of physical and social context but also the interplay between the two. The PIA layered map and hierarchy of architectural features provides an understanding of the physical context of an inhabited urban environment in the form of a graphical, people centered, representation. It highlights key properties of a particular space in an understandable and easily extractable way. The SOPHIA conceptual framework provides an understanding of the social context of a built urban environment in the form of a hierarchy of themes. It describes key properties of situated social interactions and through a qualitative, but structured, story about how people experience physical space and how they interact with each other while socializing in these spaces. Combined, PIA and SOPHIA provides a method for understanding of the socio-physical context of an urban environment.

7.2. Informing interaction design for a socio-physical context

The second guiding question for the research presented in this paper was how understanding the user's socio-physical context could inform design of a digital layer of pervasive computing for urban environments. In response to this question we have proposed an iterative, creative process as a way for interaction designers to incorporate this knowledge into their design. This process is based on design sketching in combination with systematic development of design ideas from PIA- and SOPHIA-type representations of socio-physical context. Through the development and evaluation of our prototype application, Just-for-Us, we have reflected on the value of this approach.

The design of the Just-for-Us prototype is very tightly coupled the understanding of the socio-physical context of the urban environment it was intended for. As illustrated in table 1 and 2, each of the seven design ideas making up the basics of the Just-for-Us system can be traced back to specific elements of the understanding generated through PIA and SOPHIA. Five of the seven design ideas were developed on the basis of the combined architecturally and sociologically derived understanding of the socio-physical context of the urban environment of Federation Square. *Location by district (1)* and the use of *augmented photorealistic depictions (2)* both respond to the combined socio-physical understanding of the space. They do so by utilizing, for example, the presence of distinctive and focal structures, districts, obscured places and entrances, open spaces with visible surroundings and activities around the edges *as well as* the way people use physical affordances, past experiences with a space. They index to visible elements and objects to collectively deal with uncertainty and gather information about the environment around them. Without the combined understanding represented in the outcomes from PIA and SOPHIA, these two design ideas, and their specific implementation in the Just-for-Us prototype system, would not have had the same depth and richness. Only from the combined qualitative understanding of peoples' use of the physical space,

and the quantitative understanding of the actual properties of that physical space was it possible to develop these ideas.

The value of the combined socio-physical understanding of the context of Federation Square also comes to show in relation to the development of the idea of using *rich descriptions for navigation (3).* This idea can be quantitatively strongly traced back to understandings about nodes, edges and paths originating from the architectural part of the investigation as generated through the PIA method (see tables 1 and 2). The understanding of people's use of familiar paths, as a part of their physical familiarity with a place, was derived from the sociological part of the investigation. Both played equally important roles in the development of a design that takes into consideration people's actual use of a space over time. Not only could our rich descriptions for navigation refer to the prominent physical properties of a space, they could also refer to well-known interactions there in terms of places and paths that people are familiar with. Similarly, the idea of *representation of people and activities (6)* can be traced back most strongly to understandings originating from the sociological part of the investigation generated through the SOPHIA method. However, the development of this design idea was as strongly influenced by one of the observations captured by PIA highlighting a major presence of "activity places" at Federation Square. Again, in informing the design of a pervasive computing system, the strength of the proposed approach lies in the richness of the combined, socio-physical understanding of the urban environment context being designed for.

Only two of the seven design ideas, *use of history (4),* and *meeting and waiting (7),* were not derived from a combination of outcomes from PIA and SOPHIA. These two ideas respond to understanding captured in the SOPHIA framework dealing largely with experience *over time* and of *other people* in an urban environment rather than with the physical space itself. Naturally, these highly human-centered factors are hard to capture with pure architectural methods and techniques. This emphasizes the importance of a combined socio-physical approach sensitive to both aspects of context when designing pervasive computer systems for urban environments.

Based on the findings from our user-based evaluation of the Just-for-Us prototype system, we found that the design ideas developed on the basis of our socio-physical understanding of context at Federation Square were, indeed, successful at delivering the user experiences aimed for. The implemented design successfully created a pervasive digital layer of information for an urban environment that tied directly into the existing physical and social layers of that space, acknowledging and reinforcing the interrelationship between the three. Positive user experiences of the prototype system could be traced back to elements in the interaction design of Just-for-Us that were informed directly by our understanding of both physical and social context as represented in the outcomes from PIA and SOPHIA. When given access to the described digital layer of pervasive computing at Federation Square, people were able to overcome some of the limitations of the physical layer of the environment. At the same time they used elements of this layer as anchor points for the social and digital layers. They were able to access otherwise invisible information about places and people around them and obtain an overview of what was happening and where people were gathering. They were

also able to string together their situated interactions at Federation Square over time, and share this with their friends. The socio-physical understanding of urban environment context provided by the PIA and SOPHIA methods was necessary for creating these user experiences.

7.3. A socio-physically informed development process

Based on our experiences, we propose a socio-physically informed approach to pervasive computing interaction design for urban environments (figure 6).

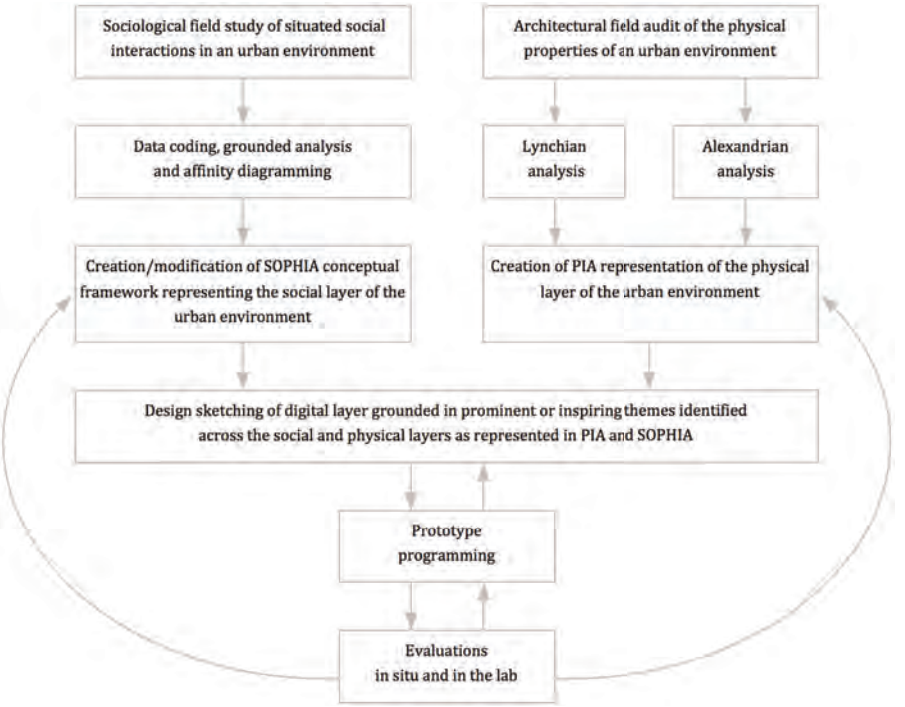


Figure 6. Socio-physical development process for pervasive computing in urban environments

The process depicted in figure 6 combine architectural and sociological streams of field studies and analysis towards the creation of PIA- and SOPHIA-type representations of the socio-physical context of an urban environment. The architectural stream involves field audits and analysis guided by the techniques of Lynch and Alexander. The sociological stream involves field observations and contextual interviews. This activity could be guided by, for example, the SOPHIA conceptual framework presented in this paper, McCullough's (2001) typology of "on the town", or it could be open-ended in its focus. The data collection activity leads to an activity of grounded data analysis and affinity diagramming. The two streams of research then feed understanding of the socio-physical context of the urban environment into a creative process of grounded design sketching of a digital layer of pervasive computing. Following on from this activity, the process takes the shape of a traditional prototyping process through which design ideas are iteratively implemented, evaluated, and refined until a satisfactory product outcome has been reached. However, as illustrated in figure 3, and described in the findings

section above, studying the user experience of a pervasive computing prototype system in situ often leads to more knowledge about the socio-physical context for which it was designed. This means that additional understanding may have to be fed back into the PIA and SOPHIA conceptual frameworks, which again may lead to the emergence of new design ideas or refinement of existing ones.

7.4. The open-endedness of PIA, SOPHIA and the seven design ideas

It is important to notice that PIA and SOPHIA are not complete methods and have not generated complete frameworks and representations. Neither is the list of design ideas, which emerged from these frameworks, a complete collection of design outcomes possible to derive from the understanding encapsulated herein.

PIA and SOPHIA have both generated specific summaries of the context of Federation Square, and we do not claim that their outcomes are generally valid for all urban environments. The level of generalizability of the PIA and SOPHIA methods and their outcomes can only be determined through repeated studies in similar as well as different types of urban environments. In terms of the outcome, repeating the described socio-physical investigation in other urban environments would possibly confirm aspects of the presented conceptual frameworks, but would most likely also extend them with further concepts and categories. In terms of the methods, it is our belief that the two approaches would be able to capture the essence of the socio-physical context of sites other than Federation Square.

In terms of generalizability, however, it is also important to notice that PIA and SOPHIA differ fundamentally in what they are capturing. PIA provides understanding that is very specific to a certain physical environment being designed for. The combination of Lynch's and Alexander's approaches to architectural analysis supports this by providing a set of physical features to look for and PIA provides a combined way to represent the outcome of such analysis. In contrast, SOPHIA provides understanding that is potentially more generally applicable to situated interactions in urban environments. This is the case because the SOPHIA empirical study is based on a broader empirical foundation, and because the data analysis process was grounded towards the creation of general concepts rather than top-down from a set of pre-determined ones. The value of combining this top-down architectural and bottom-up sociological approach lies in the potential to provide focus as well as scope. The architectural part of the investigation adds focus on the physicality of situated interactions to the sociological analysis. In return, the sociological part of the investigation broadens the scope of the architectural analysis by highlighting the role of sociality.

The seven design ideas presented are, in a similar way, specific to the particular team of designers working on the Just-for-Us prototype and their creativity at the time. Other designers, or even repeated design sessions with the same designers, would most likely generate more ideas. Hence, the design-idea dimensions of tables 1 and 2 are not complete, and can never be. Adding to this open-endedness, extending the outcomes provided from PIA and SOPHIA with additional understanding through further investigations of socio-physical context of urban environments would undoubtedly expand the design-space with more ideas.

8. CONCLUSIONS

Hybridized spaces, in that they blend the physical digital and social, challenge our current conceptions of technology, and our approaches to understanding and designing. As we learn from our reference disciplines, sociology and architecture for example, we can return the favor with our own insights and collectively strengthen our response to a significant digital challenge; the 'turn to the social' and indeed physical that is implicit in the pervasive agenda. Later work should examine the value of our approach more generally, and contribute to our collective ability to compellingly situate interaction in the built, the social, and the increasingly occupied digital space.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of the David Hay Postgraduate Writing-Up Award, the Danish Technical Research Council through the Indexical Interaction Design project, the participants themselves and Federation Square itself. We would also like to thank Keith Cheverst and Malcom McCullough for their constructive reviews of the PhD thesis associated with this project.

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Chapter 9

Sketches and mock-ups

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Abstract. Intimacy is a crucial element of domestic life, and many interactive technologies designed for other purposes have been appropriated for use within intimate relationships. However, there is a deficit in current understandings of how technologies are used within intimate relationships, and how to design technologies to support intimate acts. In this paper we report on work that has addressed these deficits. We used cultural probes and contextual interviews and other ethnographically informed techniques to investigate how interactive technologies are used within intimate relationships. From this empirical work we generated a thematic understanding of intimacy and the use of interactional technologies to support intimate acts. We used this understanding to inform the design of intimate technologies. A selection of our design concepts is also presented.

1. INTRODUCTION

Artifacts have commonly been used to mediate intimate relationships. Over the ages, intimacy has been mediated through symbols of affection such as flowers, missives and love letters. New and emerging technologies have also been appropriated to mediate close personal relationships. In particular, we observe this appropriation with the Internet and mobile phones. It is now commonplace for family members separated by distance to maintain contact via the Internet. Matchmaking and online dating are popular Internet services (Donn and Sherman 2002). SMS (Short Message Service), i.e. sending a text message via mobile phone, is increasingly being used to forge new romantic relationships (Byrne and Findlay 2004) and to coordinate activities with intimate friends (Grinter and Eldrige 2001).

Even though an intimate relationship often requires no mediation, new technologies are regularly manipulated to help us feel connected with those for whom we care.

Originally published as Vetere, F., Gibbs, M., Kjeldskov, J., Howard, S., Mueller, F., Pedell, S., Mecoles, K. and Bunyan, M. (2005) Mediating Intimacy: Designing Technologies to Support Strong-Tie Relationships. In *Proceedings of CHI 2005,* Portland, Oregon, USA (pp. 471-480). New York: ACM.

So strong is this desire, that we will spend significant amounts of money on communication technologies, and will be inconvenienced by poor usability so that our personal relationships are nurtured and maintained. For example, young people will endure SMS even though it lacks expressiveness, it has confusing syntax and it is prone to errors (Grinter and Eldrige 2001). However, it satisfies an important social and personal need to feel connected. The strength of this desire together with the inadequacy of current technologies to support expressions of intimacy, offer a unique research opportunity.

In this paper we are interested in phenomena that are recognizably intimate – expressions of tenderness, acts of devotion and habits of demonstrable affection. We are interested in understanding how technologies are used to support these phenomena and in investigating methods for designing new ICT (Information and Communication Technologies) for mediating intimacy. This is not simply a question of creating representations for expressing emotions, as for example emoticons attempt to do. Rather it is a broader exploration of the role of ICT in people's intimate lives in order to create more fulfilling designs.

2. ATTEMPTS TO MEDIATE INTIMACY

There is a growing interest in technologies that support relationships with intimate others (Bell et al. 2003). For instance Gaver (2002) proposes provocative ideas for connecting people in close relationships. He describes technologies that provide a feeling of presence of remote lovers through peripheral awareness. Examples of awareness technologies are: a feather in a plastic cone that floats when the distant partner picks up a picture frame of the couple (Strong and Gaver 1996); a light 'orb' that glows in New York when a family member walks into their London apartment (Tollmar and Joakim 2002); and two sets of cylinders that roll and rotate in unison as they are manipulated by separated partners (Brave and Dahley 1997). Through a critical analysis and review of awareness technologies, Gaver identifies three typical characteristics: (i) the designs often make use of evocative materials (such as feathers and scents); (ii) mappings are more likely to make use of literary rather than didactic metaphors (e.g. rolling cylinders that evolve into tactile languages); and (iii) objects have a unique physicality (e.g. a real feature is more poetic than one simulated on a screen).

These characteristics are common in technologies for mediating intimacy. For instance, Kaye and Goulding (2004) presents three Intimate Objects that address the problem of close couples trying to maintain feelings of intimacy when separated by large distances. These objects are intended to be used by a specific couple (i.e. custom built) for communicating intimacy specifically (e.g. not used for work-related activities). The first object is How do I love thee, a pair of abacus, whose beads are synchronized over the internet. Next is Hand Holding, devices that simulate the warm touch of holding hands. Finally is Love Egg that rolls on a concave dish when an intimate message is left on its messaging system. These objects display each of Gaver's three characteristics. They use evocative materials (soft silicone in Hand Holding), exploit non-didactic metaphors (positioning abacus beads) and have a unique physicality (shape and texture of an egg).

Another intimate object with a dominant physicality is the Sensing Bed (Goodman and Misilim 2003). The Sensing Bed comes in pairs, and is intended for romantic couples who are not co-located. The bed senses the body position of one person and transmits warmth to congruent parts of the lovers' bed. The Sensing Bed is similar to the Bench Object (Gaver 2002), which has a seat that warms when somebody sits on a partner bench far away. Unlike the Sensing Bed, the Bench Object is public. The warmth on the Bench Object is generated by an unknown other (and so the effect is often disturbing). Even though the Sensing Bed and the Bench Object are technologically similar and both exploit peripheral awareness and physicality, their intent is different. The first is intended for couples in an established relationship, the latter is intended to provoke a visceral response between strangers in a public place. It is with the former that our work is more closely aligned.

A study concerning intimate relationships of a different kind comes from a group of students motivated by the routine of emptying their pockets of coins and keys when arriving home. They recall that the clanging of keys on the table is often followed by the cry "Mom, I'm home". The researchers exploit the association between the clang of keys and the arrival call to create the Gustbowl (van der Hoog et al. 2004). When items are thrown into the Gustbowl, the bowl wobbles and takes a picture of the items. The picture and the movement are transmitted over the Internet to an identical bowl that wobbles and receives the picture. The Gustbowl is intended to support the strong-tie relationship between mother and grown-up son. It is non-verbal, using pictures and sounds to trigger meaning from established routines and behaviors.

A comparable study, the ASTRA project (Markopoulos et al. 2004), is also concerned with family members living apart, but focused on the interrelationships within the family rather than one-to-one relationships. Their motivation is to understand the role of peripheral awareness systems in social interactions within families.

3. CHALLENGES FOR STUDYING MEDIATED INTIMACY

Intimate relationships are different from the kinds of relationships that have been typically studied by HCI research. Intimate relationships are different to those found in the workplace or amongst social networks of friends. Intimate acts also differ from the domestic behaviours usually addressed in the literature [see 15 for a review]. Attempting to study acts of intimacy presents the researcher with a number of unique and interesting challenges (Kjeldskov et al. 2004). Studying intimacy is challenging because intimate acts are ephemeral and transient yet ubiquitous and crucial to the ongoing life of an intimate relationship. They form the material and background of close personal relationships, yet occur in the doing and then often vanish unremarked. While the informational content of intimate acts may be low and seemingly trivial to outsiders, the act itself can be laden with emotional significance for those involved. Intimate acts often entail self-disclosure, and thus privacy is a concern. Much of what passes between intimates is unsaid and premised on deep knowledge and understanding of one another and occurs in the context of a rich, shared and sometimes idiosyncratic view of the world that may be difficult for others to fathom and comprehend. Intimacy also involves assumptions about commitment and mutuality. It carries nuanced expectations for

reciprocity and exchange that are negotiated and arrived at over many years, yet remains fragile and is occasionally misjudged leading to misunderstandings and conflict. Finally, unlike instrumental tasks (e.g. coordination of family activities), or leisure activities (e.g. games) there is no generally accepted language for describing and discussing intimacy, especially in relation to designing technologies for its support.

In designing our research, we were mindful and sensitive to the challenges presented by studying intimate acts in the domestic setting. In responding to these challenges we wanted an approach that enabled us to maintain a longitudinal presence in the field so we could study the ongoing life of relationships. We were keen to capture the ephemeral and "unsaid" (Geertz 1973) aspects of intimate exchange and needed an approach that enabled intimate acts to be recorded as they occurred, or soon after. Given the private character of intimate relationships, we were keen to empower our subjects as participants in the research and to give them control over what was, and was not, revealed to us. Since intimate acts are highly nuanced and often subtly ambiguous to outsiders, we wanted to provide participants with materials enabling them to interpret and explain their practices to us. Finally, we wanted an approach that allowed us to carry out an ongoing conversation with participants and through this conversation arrive at a shared understanding of intimacy and the place of ICT in mediating intimate acts. We describe this approach in the next section.

4. RESEARCH DESIGN

Other researchers who have had to confront the difficulty of investigating personal relationships have adopted a range of research methods. These include: online questionnaires and surveys (Byrne and Findlay 2004, Donn and Sherman 2002); data logs (Grinter and Eldrige 2001); longitudinal focus group (Taylor and Harper 2003); interviews (Kaye and Goulding 2004); and written reflections (Pedell et al. 2003). Since our goal is not only to understand intimacy, but to design for it, we adopted a suite of methods and techniques. Our research plan is represented in Figure 1. In the first phase of our research we sought to understand current practice. We undertook ethnographically informed field studies using cultural probes (Gaver et al. 1999) and contextual interviews to understand how people use ICT in their intimate relationships. In the second phase of our research we sought to use the insights into current practice gleaned from phase one to provoke and inform the design of future ICT to support intimate acts. In this phase, we engaged in a variety of design activities including expert design workshops, participative design workshops, scenario development and the development of fidelity prototypes.

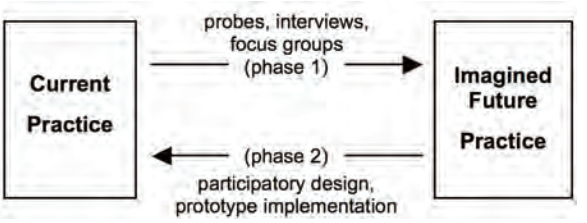

Figure 1. Cycle of use-centered innovation (Howard et al. 2002)

4.1. Method

Our approach extends the work of Gaver et al. (1999) and the Equator team (Cheverst et al. 2003) by combining cultural probes with contextual interviews and focus groups. We assembled a collection of cultural probes into a 'probe pack' (Figure 2). The probe pack contained: diaries and scrapbooks; digital camera with printer; postcards; pens, glue, and catch-phrase stickers (e.g. "I feel alone when …", "I feel supported when …").

Figure 2. Contents of Probe Pack

The diaries were used individually to record daily communication and interaction activities. This included the form of communication (e.g. SMS, telephone, email, letters, notes, tokens, gifts) and other details such as time, date, location, the content and the feelings associated with it (e.g. urgency or dissatisfaction).

The scrapbooks were used to tell rich and evocative stories about communicative events and to express the technology wants, desires, likes and dislikes surrounding these events. Couples were encouraged to work together with pens, crayons, glue, photos, magazine clippings, drawings to form a montage of their intimate lives.

The digital camera and printer were used to photograph and print significant events. The docking printer provided the immediacy of traditional Polaroid photographs with the convenience of lasting digital images. Participants were encouraged to take photographs of everyday artifacts and events that express some important dimension of their interactions: e.g. the answering machine at the time of receiving some unexpected news or of a child in a football final to share with an absent parent. Participants were asked to print, annotate and cut-and-paste the photographs into their scrapbooks or diaries or postcard, as they saw fit.

The participants were asked to read and reflect on the catchphrase labels, complete them, and stick them into the diary, scrapbook or on a post card. The stamped addressed postcards were used for sending short stories or images to the researchers or to the intimate other.

Finally, an additional probe element was introduced midway through the study. This new element consisted of small printed facsimiles of a variety of mobile device screens (e.g. mobile phones and PDAs). This new element served to both stimulate engagement in the study and encourage participants to envision possibilities for future technologies

to support their relationship. Participants were invited to use these facsimiles to note design ideas and to insert them into the scrapbooks or diaries.

All the materials could be used in whatever way participants wished. The instructions were only suggestions. No time requirements were made, but it was suggested they should spend about 20-30 minutes each day using the probe pack materials.

4.2. Participants

The study involved six Caucasian couples in stable heterosexual relationships spanning between 4 and 16 years in duration. All couples cohabitated, although work related travel occasionally required periods of separation. The age of participants ranged from late 20's to late 40's. Three couples had children, ranging in age from 18 months to 12 years of age. In one case the children were from a previous marriage. The couples could be broadly described as middle-class, leading professional lives in urban environments. The couples were neither very rich nor very poor, though some were reliant on government subsidies. The participants all had tertiary qualifications with occupations as Social Worker, Charity Worker, Business Analyst, Industrial Relations consultant, IT consultant, IT trainer and Journalist. Two participants were undertaking full time higher education, and one worked as a casual administration officer while caring for young children. All couples had access to the Internet and mobile telephony. They used a variety of electronic media such as landline and mobile phones, email, Internet chat, SMS and fax to communicate with each other, although the exact mix of technologies used by each couple varied markedly. The number of participants in our study is comparable to that in other probe research (Gaver et al. 1999; Hutchinson et al. 2003).

The participants were recruited through calls via email, posters and personal contacts. The participants were allowed to keep the digital camera and docking printer as appreciation for their participation in the study.

4.3. Data Collection

Cultural probes were deployed for a period of seven weeks. This period was followed by focus groups and design workshops.

Week 0: Probe pack distribution and initial interview

An initial interview was carried out at the participants' homes. This included questions about the participants' backgrounds, their relationship, their communication habits and their use of technology. Following the interview, the researchers presented the cultural probe materials and informed participants of their use.

Week 1: Interview and process checking/steering

A week after the probes were distributed, researchers visited the participants' homes for a second time to answer questions about their use of the probes and to discuss activities of the first week.

Week 4: Interview and addition of new probe element

Researchers and participants discussed the materials accumulated through probe activities, and participants were encouraged to clarify, elaborate and reflect on the

materials they composed. At the end of the third session, researchers introduced the printed mobile device screen facsimiles.

Week 7: Interview and probe collections
Diaries, scrapbook and other materials such as design ideas produced on the mobile device screen facsimiles were discussed. This session was used to bring closure to the seven-week process. All materials gathered through the cultural probes were retrieved at this time

Week 9: Focus groups
Several weeks after the probes were collected, participants in the study were invited to take part in one of two focus group discussions. In these sessions, we presented our preliminary themes to participants and invited them to comment and reflect on them. Their contribution was to refine and consolidate the intimacy themes.

Week 12-15: Design Activities
Intimacy themes identified during data analysis (see below) were used to motivate design ideas through three activities. We firstly conducted a series of brainstorming sessions, then a design workshop with HCI experts, and finally a participatory design with those involved in the study. The outputs of these activities were high-level descriptions of technologies to mediate intimacy, and development of a prototype to demonstrate a subset of design ideas. The design process is only partially reported in this paper.

4.4. Data Analysis

Six researchers were involved in data collection and analysis. Researchers worked in pairs with participants. Analysis and interpretation of data began immediately. Following each meeting with participants, the researchers who conducted the interview would meet to discuss the probe traces and interview contents using an open-ended process of rapid reflection (Pedell et al. 2003) to identify important themes, ideas and concepts that emerged from their encounter with the participants. They would then compose a summary of the interview and this summary, along with the themes identified was reported back to the larger research team at weekly meetings.

At these weekly meetings themes emerging from the data were explored, debated and discussed. The probe data was naturally incomplete, unclear and biased (Gaver et al. 2004). This inevitably led to subjective interpretations where the data was often discussed in terms of the researchers' own experiences of intimacy. These ongoing discussions around the data and its analysis continued throughout the project and the themes identified in the data were refined iteratively. Data integration meetings were held at critical stages of the project. At these meetings, data and interim analyses were presented and debated. These meetings helped to develop and refine dominant themes. Finally, focus group discussions were held with participants in the study. These focus groups allowed the participants to make a final contribution and comment on our observations and findings.

5. FINDINGS

Despite numerous social science studies of intimacy and the exchanges that occur within intimate relationships, a universally acknowledged definition of intimacy has yet to surface. Of those definitions that have emerged (for example Cheal 1987; Moss and Schwebel 1993; Register and Henley 1992; Robson, D. & Maggie 1998) few provide any significant design traction.

Figure 3 presents a schematic view of the primary themes induced from our qualitative data. The themes are placed according to affinity with their neighbors. Whilst each theme is evident in our data, they overlap to a significant degree, and the affinities we have tried to reveal in the structure of Figure 3 are complex and multidimensional; in truth the diagram could be rendered in many ways, with each alternative giving preference to different themes.

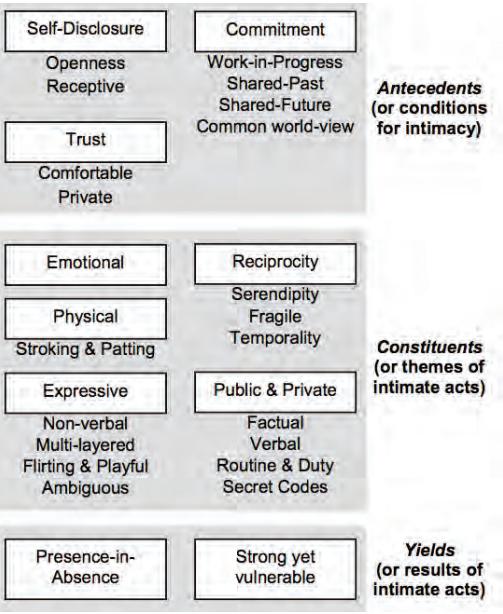

Figure 3. Antecedents, Constituents and Yields of Intimacy

We've found it useful to think of intimacy in terms of those themes that precede its experience, Antecedents; those themes that characterize the act(s) itself, Constituents; and those themes that reflect the consequences of an intimate exchange, Yield. Figure 3 is structured according to these three clusters, before, during and after. So, for example, 'Commitment' is an antecedent or a pre-condition of intimacy. Being 'Emotional' is better considered an expression of intimacy, and so characterizes something about the intimate act itself. 'Presence-in-absence' is a feeling that results from an intimate exchange or an intimate thought, and so is a yield of intimacy. Of course, Antecedents and Constituents exist in a recursive relationship, and our so-called Antecedents can, over time, also be a consequence of intimate acts. The sub-themes are grouped and clustered around a central theme (shown as outlined boxes in Figure 3).We now illustrate the central themes, drawing on our data where useful.

5.1. Before Intimacy: Antecedents

Self disclosure

The price of intimacy is revelation and mutual openness (Monsour 1992; Moss and Schwebel 1993). It is during self disclosure that we 'get to the heart of the matter'. An act of self disclosure carries with it an expectation that it be returned in-kind, and a failure to reciprocate is felt keenly as a breakdown in the maintenance of intimacy. One participant completed the catchphrases "I misunderstand my partner when…" with "… he goes quiet." The maintenance of 'partner awareness' rests on an almost constant background of chatter and stroking that both reveals and acknowledges each others' internal state; "I really need to tell my partner…" is completed with"…what happens during my day and for him to tell me about his; it feels right."

Trust

Intimacy requires trust and sincerity. The self disclosure that so keenly illustrates an intimate act risks both the self and the other, and that risk demands trust. Intimacy also requires a commitment to the relationship as something bigger than oneself (Cheal 1987). The trust that characterizes strong-ties is deep and resilient, allowing each partner to be playful and flirtatious without any real risk to the relationship. This is exemplified by a participant who sent a sexually provocative text message to her partner, knowing that he was in a pressured business meeting. She was being playful and feeling sufficiently secure to risk provocative behavior. Their shared commitment extended beyond the act itself. The levels of trust and mutual commitment we observed provide a robustness against the negative effects of communication breakdowns; with trust comes tolerance for the inevitable little fractures in the intimate dialogue (e.g. failure to return a call within an expected time window) but a raised expectation for a deeper reciprocity.

Commitment

Commitment is the extent to which partners in a relationship perceive their relationship as ongoing for an indefinite period, and is a precondition for other aspects of intimacy to flourish (Chelune et al. 1984). Some of our participants framed this as being on a "shared" or "common journey" together. They shared both the costs and rewards of lives together. Features of participants' lives, such as raising children, caring for older relatives, maintaining the household, or traveling to work, were all enterprises that were shared and, in the sharing, became vehicles for enacting, affirming and maintaining their relationship. Joint responsibility was taken for domestic life, including activities such as paying the bills, transporting children and preparing meals. These activities were often coordinated on the fly using interactive technology such as mobile phones. The division of labor within these relationships had regular patterns but was also fluid and renegotiated over the course of a day. Responsibilities also provided occasions for affirming the relationship. For example, the success of a child at school was affirming "our" achievement as "good parents". Even activities that were the sole responsibility of one member of the relationship became joint enterprises. Participants reported drawing on their partner's help and skills for work related tasks such as database development, setting up a web-based email account or writing a job application. Being able to help and share common tasks affirmed the relationship and sense of moving through the world together as a team, rather than as individuals.

5.2. During Intimacy: Constituent Themes

Emotional

In contrast to the routine and dutiful exchanges that characterize much work activity and family life, for example the coordinative activities that occupy much of parenting, intimate acts mediate emotion (Moss and Schwebel 1993). In intimate acts the medium can indeed be said to be the message; within most relationships, there is little new information exchanged in saying "I love you", but few would argue against the value contained in its saying!

Reciprocity

Though many intimate exchanges are asynchronous, there remains a strong sense of reciprocal binding. At the atomic level, the utterance "I love you" demands to be answered in like terms; it is unimaginable that such an exchange be met with ignorance. In more general terms, intimacy depends on intimates who are co-engaged in a common cause (Moss and Schwebel 1993).

An example of reciprocity is the 'goodnight message' (Grinter and Eldrige 2001). One couple would insist on sending each other text messages late at night when one person was working a night shift. The recipient lies in bed, turns the phone volume down and awaits the incoming message. The preparation and expectation is part of the reciprocity of their imitate relationship.

Expressive

These are non-verbal but highly expressive interactions often involving playful, even ambiguous exchanges. Though intimate acts are not fact-free acts, the centrality of emotion to their meaning gives them a special quality. Intimate exchanges can themselves become the subject of 'personal innovation'; our intimates strive to keep the conversation of intimacy alive and fresh by changing its form or medium, often in playful ways. For example, Figure 4 shows a section of a scrapbook, where a participant used pictures to express his love. In another case, a participant would hide messages in places their partners are likely to visit (e.g. underwear drawer). These gifts would be discovered later serendipitously; the element of chance involved in the discovery merely added to the experience of receiving the gift, rather than being something to be 'designed out' in an attempt to make the gift giving process more 'efficient' or 'effective'. "Having fun, being creative and using humor is something we like to do".

Figure 4. Being creative and expressive.

A clear distinction existed between those participants who were parents, and those who were childless. The presence of children in a household colors all interaction, including intimacy. In comparison to child free couples, working parents are time poor to a highly significant degree. Where child free couples wish to experiment with the language of intimacy in playful and creative ways, working parents strive to reclaim space to 'be

just us again'; their need is less for playful new ways of saying 'I love you' than it is for reclaiming opportunities to interact as a couple. Couples with children routinized time together, often late in the evening after children are bathed and put to bed.

Physical, involving stroking and patting

Intimates communicate in often non-verbal but nevertheless highly expressive and nuanced ways; ways not well supported by current technologies that are biased towards verbal language and encoding information. The physical expression of intimacy includes but is certainly not limited to sexual relations. Our intimates stroked and touched each other in gentle ways when co-present, and exchanged gifts that had physicality and could therefore act as a proxy when the partners were distant in space and/or time.

Public & Private

While much that is associated with intimate acts is quintessentially private in character, intimate relationships also have public expression. Couples present a 'face' to the world, that both affirms to themselves, and to others, their status as a couple (Goffman 1959). This can occur through ephemeral public displays of affection, such as touching and kissing in public, or more concretely through the public and legal declaration of love and commitment entailed in marriage. While public, these expressions of self were also often highly nuanced and coded, allowing for the private communication of meaning in a public forum.

Intimate relations are rich sources of private covert language. Often obscure ("NYUM" meaning yummy or delicious and '143' meaning 'I love you') and sometimes containing hidden meanings ("It is very simple really" said during difficult times to refocus the couple onto what is really important in life, i.e. 'us') they define their partners as distinct from the world and mediate their relations, allowing private interactions in public places whilst limiting the risk of being 'overheard'.

5.3. Consequences of Intimacy: Yield

Presence-in-absence

We frequently observed intimate exchanges when couples were face-to-face, and indeed it was surprisingly common for those exchanges to be mediated by technology. For example, participants sending an intimate text message from the living room to the bedroom, or from one floor of an office building to another floor, or sending an email to a partner who is working on another computer a few meters away. Email and SMS were used to facilitate stroking and patting behavior. However, perhaps the most vivid expression of the centrality of intimacy to our participants' lives came with the elevation of 'presence-in-absence' to a core need. When separated by distance or time, our intimates described a strong sense of presence-in-absence, a sense of the other despite their physical absence (Register and Henley 1992). Our participants invested considerable time, effort and emotion in ensuring that their partners stay with them, at the forefront of their hearts and minds, throughout daily life. A good example of where presence-in-absence was missing is shown in Figure 5. The child is proud of having built a house of cards, and would very much like to show his father who was away on work duties. The ephemeral tower was captured by a photograph to be shown to him later.

Strong yet vulnerable

Our study has also taught us that it is important not to romanticize intimacy. Intimacy and the tight emotionally charged bonds it entails are strong, yet can be strangely and unexpectedly fragile.

While relationships may be robust, misunderstanding and misinterpretations do occur. When they occur, these breakdowns can have serious repercussions, creating ill will and emotional hurt that can obstruct and undermine intimacy within the relationship. When one participant was angry with his wife, he would put his mobile phone on the mantelpiece, declaring through his actions that he was unavailable. The phone represented a connection to his wife because it was used almost exclusively to talk to her. By placing it on the mantelpiece, he indicated that he did not wish to 'carry' her. Another couple had a routine of coordinating their departure from work each evening so that they could catch the train together. When as a result of an unexpected meeting one person caught the train without notifying the other, resentment and anger ensued. Such a fallout from a simple breakdown in understanding between partners can reverberate through the relationship for days, if not weeks. For these reasons, any interactive technology designed to support or mediate intimacy should mitigate against these forms of breakdown, allow repair of them when they do occur, and contribute to relationship stability.

Figure 5. Entry in one of the diaries. "Hi Dad. I've been making card houses and mums been taking photos. She wants to talk to you …"

6. IMPLICATIONS FOR AN 'INTIMATE TECHNOLOGY'

Based on the findings, we have developed a series of design ideas. This process had three phases. First, the research team conducted a brainstorm session to produce a series of design sketches. These designs were highly abstract, often consisting of a schematic drawing, a short description and keywords linking the ideas to the themes of intimacy emerging from our empirical data (Figure 3). Second, we conducted two one-day design workshops. One workshop was with experts in human-computer interaction design and the other workshop with couples participating in our earlier ethnographic study. Third, we developed and implemented a functional prototype to demonstrate some of our ideas and concepts. A selection of our design ideas are presented below.

6.1. Preliminary Design Sketches

The brainstorming of design ideas resulted in the development of 22 design sketches. The designs produced at this time were highly diverse, addressing a range of requirements, opportunities and challenges identified in our user study. Most of the ideas involved mobile as well as stationary devices, visual as well as auditory and tactile interfaces and explicit as well as ambient interaction. For example, we discussed several personal devices that would enable partners to interact unseen with each other throughout the day via low-fidelity communication channels. One of such devices was the "Secret Touch" (Figure 6), which enables partners to "virtually hold hands" while physically separated. The Secret Touch device allows partners to exchange tactile impulses over the Internet by padding or squeezing the device in their hand or pocket. At the receiving end, these pads and squeezes would be emulated as vibrations, heat or pressure.

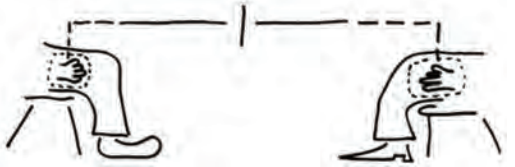

Figure 6. Secret Touch: handheld devices allowing partners to make secret tactile exchanges while physically separated.

6.2. Design Sketches from Workshops

The design workshops we conducted with interaction design experts and study participants produced significant results. Over two separate days, six groups of 4-5 people produced a refined design sketch that included: (i) a description of the functionality of their system, (ii) a central screen design, (iii) a basic interaction design, and (iv) a scenario of use illustrated with drawings, pictures and text.

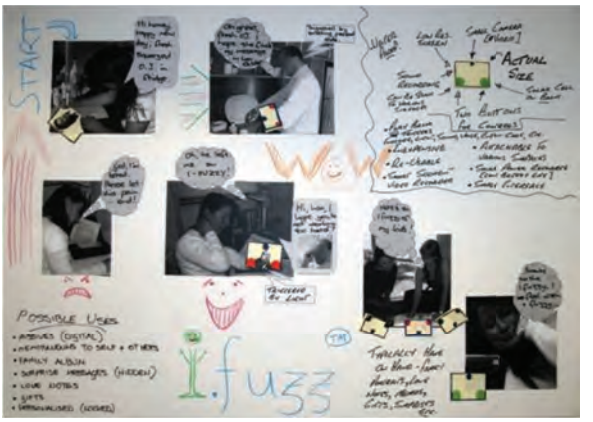

Figure 7. Poster for the mobile device 'i.Fuzz' produced in the participatory design workshop

One of the designs was a mobile device called i.Fuzz (Figure 7). The idea of the i.Fuzz concept is to provide a simple digital analogy of common analogue media, such as postcards and post-it notes. The i.Fuzz would be a cheap, light-weight, semi-disposable multimedia appliance that enabled pre-recorded messages to be left at different physical

locations to be serendipitously discovered by one's intimate other. The i.Fuzz devices should thus include memory, processing power as well as facilities for recording and playing back audio and video. An example scenario, derived from our user study, illustrates i.Fuzz use. A missive for one's partner is left in their sock-drawer on an i.Fuzz pre-programmed to start playback when the drawer is opened in the morning and the i.Fuzz exposed to light. Other envisioned uses of the i.Fuzz included using it as a digital keep-sake or to carry video clips of one's children.

Importantly, this scenario is taken from the participants. A participant left a message of affection on a piece of paper hidden in a sock drawer before leaving for work. This story was an inspiration for the design workshops. It nicely encapsulated the playful, the emotional and the private themes of intimacy, and led to a feeling of presence-in-absence when the message was eventually found.

On the basis of the design sketches produced by the research team and in the two workshops, we produced a number of more refined designs and implemented a functional prototype. Some of these are described below.

6.3. SynchroMate

A more refined design responded to the user study observation that partners would sometimes send and receive messages simultaneously via SMS or email. The messages seem to "cross each other in the air". These coincidences, of receiving a message from someone while simultaneously sending that person a message, had a lasting impact on the couples. The coincidence was attributed with almost metaphysical significance, such as "a stroke of faith" or "indicating a special personal connection".

SynchroMate is a round device attached to the palm that aims to assist this "faith" a little and to make this metaphysical event more likely. It supports serendipitous synchronous communication by exchanging not only the message itself but also that a message is being composed. The SynchroMate allows intimate couples to 'stretch time' by allowing the serendipitous moment to last a little longer and to provoke anticipation. This device helps to express themes of reciprocity and serendipity.

6.4. Hug Over a Distance

Another of our early ideas took a step towards wearable computing and smart clothes; equipping partners with jackets providing couples with an open, physical and ambient channel of interaction, and enabling them to exchange a 'hug' while physically separated.

In the original idea for the Hug Over a Distance a person would be able to initiate a hug causing their remote partner's jacket to emulate, in some fashion, the feeling of a hug. This remote hug could then be rejected or reciprocated by the remote partner. When reciprocated, the jackets would remain synchronized in 'hug mode' until either of the parties chose to end the hug. This design idea was inspired by several of the themes of intimacy identified through our field study. It supports stroking and patting in a non-verbal but physical way. It is flirtatious, playful and it involves a high degree of reciprocity. Also, it permits couples to express private and discrete signs of affection in public places; a behavior identified by several of our participants.

We chose to implement a simplified, one-way version of Hug Over a Distance as a functional prototype (Figure 8) because it allows an immediate tactile interaction with an emotional content (similar to holding hands or giving a hug) and it can be used anywhere, anytime, yet discreetly and unobtrusively.

Figure 8. Hug Over a Distance prototype: showing pump, valve, battery, relay controller and wireless PDA. During use, these components are hidden inside the vest.

Hug Over a Distance uses two PDA devices connected wirelessly through TCP/IP via WiFi or through mobile phones via Bluetooth. One PDA is embedded in an inflatable, yet tastefully tailored sleeveless jacket. The other PDA is carried by the partner. If the PDA in the jacket receives a hug request, air channels embedded in the jacket are inflated to create a light, but palpable pressure on the body. After four seconds of pressure, an electronic valve opens and releases the air. The PDA sends an acknowledgement saying the hug was received, and thanks the sender with a kissing sound.

It is important to emphasize that we are not intending to recreate accurately the physical experience of a real hug using technology. Rather, we want to demonstrate, using a piece of wearable computing, that it is possible to send an emotional "ping" to a remote loved one with a tactile and unobtrusive interface. We are referring to a "hug", because the feeling of light pressure surrounding the body combined with the associated warmth is most closely related to a hug.

7. DISCUSSION

In this paper we have reported on ongoing work exploring designs ideas and concepts for technologies to support intimate acts. The significance of our contribution is threefold. First, we have presented an effective method for studying mediated intimacy in the 'wilds' of everyday life. Our approach used and interlaced cultural probes, contextual interviews, technology provocations, and participant observations to produce rich qualitative data of everyday situations of use. This approach is also applicable to the study of other forms of practice in the domestic environment.

Secondly, we have used these empirical materials to produce a nuanced and detailed understanding of mediated intimacy. This analysis and the thematic model produced have led to profound insights into the current role of technologies in intimate lives. It has also provided an empirically grounded springboard for inspiring and informing the design of future intimate technologies.

Finally, our various design activities, which included brainstorming sessions, and expert and participant design workshops generated a large number of design ideas. We have presented a small selection of these design ideas and concepts. In addition, one of these – Hug Over a Distance – was developed as a demonstrator prototype.

While these designs for future technologies have not, as yet, been evaluated, they do emerge from empirically grounded understandings of current practice. Their validity is thus grounded in the real and observable practices of everyday life, as people use a variety of appropriated technologies to mediate their intimate lives. In the future, as indicated in our user-centered design approach (Figure 1), we intend to place prototypes of varying fidelity back in the field with participants in the study, as well as with other intimate couples, for evaluation and refinement of our ideas and methods.

8. LIMITATIONS

The schematic presented in Figure 3 is not a theory of intimacy. It does not explain why or how expressions of intimacy occur. Nor is it comprehensive. We do not consider likely influences on expressions of intimacy due to culture, sexual orientation, social class, age or geography. Nor is the thematic model a list of requirements. The themes are grounded concepts intended to trigger and inspire design ideas. For example, what would it mean to design for "stroking and patting", "routine and duty" and "work in progress"? These are not requirements in any traditional sense, but they may provoke further exploration of user needs.

We agree that probes are intended to "elicit inspirational responses from people– not comprehensive information about them, but fragmentary clues and their lives and thoughts" (Gaver et al. 2004). However, because we have chosen to visualize our probe data as themes, our results appear less fragmentary. We believe this helps to communicate our work without losing the power of provocation.

9. CONCLUSION

As Gaver points out communication of emotion is often not in the device output, but in the dynamics of use (Gaver 2002). Similarly the innovations presented in this paper are not specifically conceptual innovations (for example, Rosella and Sakai (2002) suggests the building of a Hug Over A Distance underwear device), but innovations of use. In other words, our design ideas and concepts are often a reconfiguration of existing technology, rather than speculation on future technology. Importantly, this reconfiguration is motivated by our understanding of current practices of intimate behavior. The innovation exists in the extensive analysis of the fieldwork and in the new uses that emerge from this reconfiguration.

Technology will never replace the physicality and immediacy of face-to-face contact. However, there is still much to understand about how interactive technologies can further augment, extend and support intimate experiences. Our work takes an important step along this path to understanding, and we hope it will encourage further work in the development of technologies expressly designed for mediating intimacy.

ACKNOWLEDGMENTS

The authors would like to thank all couples participating in the study and acknowledge the support of the Smart Internet CRC (project UE-06) and the Danish Technical Research Council (project 26-03-0341).

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Chapter 10

Ethnography and object-orientation

Jesper Kjeldskov and Jan Stage

Abstract. There has been a lot of interest in ethnography within human-computer interaction over the last two decades, and its relevance within systems development is today beyond question. However, one of the challenges reported is that ethnography generates findings and knowledge with such contextual richness that it can be hard to transfer into system design. In the light of recent years' push for the use of ethnography within the area of *mobile* human-computer interaction, this challenge has resurfaced and is of renewed importance to the research field. In this article we describe an interdisciplinary combination of ethnography with a structured software engineering method supporting the transition from collected data to design and implementation. We explore this combination through two case studies of mobile system development for supporting distributed work activities within industrial process control. We show that when developing mobile systems ethnographic data is a highly valuable source of input for developing object-oriented models by providing contextual richness, and that in turn, objected-oriented analysis is a highly valuable method for working with ethnographic field data in systems development by supporting the creation of abstract models. Combining the two, we have a method where ethnographic field studies inform core system design.

1. INTRODUCTION

In a literature review from the early 2000s (Kjeldskov and Graham 2003), it was found that the majority of research within the area of mobile human-computer interaction was based on applied research and laboratory experiments. One of the consequences of this was that research was poorly grounded in real world activities and subscribed to the assumption that we already knew what problems to solve – just not exactly how to solve them. In response to this, the mobile HCI community was urged to explore the

Originally published as Kjeldskov, J. and Stage, J. (2012) Combining ethnography and object-orientation: contextual richness and abstract models for mobile interaction design. *International Journal of Human-Computer Studies,* 70(3), 197–217.

use of more contextually grounded methods, such as ethnography, as illustrated by, for example, the work on mobility in collaboration by Luff and Heath (1998). In a follow-up review from 2010 (Kjeldskov 2012) it was found that although fieldwork is now much more common, there is still not a strong link to design and development. One of the problems with ethnography for informing design and development of computer systems is that it sometimes generates findings and knowledge with such contextual richness that it can be hard to translate into system design.

There has been a lot of interest within human-computer interaction over the last two decades in how ethnography can inform system design (Crabtree et al. 2009), and the challenge of transition from collected field data to requirements analysis has been described many times in the literature for over a decade (Paay et al. 2009, Kjeldskov et al. 2006, Constantine et al. 2003, Viller and Sommerville 2000, Hughes et al. 1994). With the push towards using ethnography within the area of *mobile* HCI this challenge has resurfaced and is of renewed importance. Hence the aims of our work presented here are similar to that of the references above, but with a particular focus on mobile computing. As our scope for this research we wish to, firstly, address the overall interplay between ethnography and existing object-orientated methods, rather than the development of new specific modelling techniques as in, or example, Viller and Sommerville (1999) and Iqbal et al. (2005). The latter, however, is an apparent opportunity for further research in light of the case studies presented here.

When designing and developing a computer system, a level of formalization is always required at some point in the process. Very often, this is where findings from ethnographic studies are lost or summarised beyond recognition, simply because they do not translate well directly into system specifications. As a consequence, even though ethnographic field studies might teach us a lot about the use context of our future systems, this knowledge is often difficult to trace through to the resulting designs. This is also the case for mobile systems.

In response to this, we have explored an interdisciplinary combination of ethnography with a structured software engineering methodology that is known for effectively supporting actual system development, namely that of *object-oriented analysis and design* (OOA&D) as devised by Mathiassen et al. (2000). The object-oriented analysis and design methodology has proven its value in systems development by producing formalized and abstract models that can be directly implemented in an object-oriented programming language (for an insightful discussion of different methodologies and representations in human-computer systems development including object-orientation see Benyon 2002). In the specific OOA&D method described by Mathiassen et al. (2000) the development of these models is done as a part of an analysis of a system's *application domain* and its *problem domain* respectively. Based on concrete experience with this method, it is our position that ethnographic field study data is highly valuable as a source of input for such application and problem domain analyses by providing *contextual richness.* In turn, objected-oriented analysis is highly valuable as a method for working with ethnographic field study data by supporting the creation of *abstract models.* By explicitly combining the two, we have a method where ethnographic field studies can influence the core of a system design. This is what we intend to show in this article.

We present our experiences with the development of two mobile systems using a combination of ethnography and OOA&D. The first case study concerned the operation of a large container ship (Kjeldskov and Stage 2003). The second one concerned the operation of a large power plant (Kjeldskov et al. 2006). We present the two development process case studies in detail, showing how they each followed the same overall process from ethnographic field studies, through object-oriented analysis and design, to conception of prototype systems that could be evaluated with prospective users. The second case study naturally built on the lessons learned from the first one, and we show how this led to modifications to the method applied.

The paper is structured in the following way. First we introduce related work. We then describe the overall method applied for our two case studies. Sections 4-9 take you through the five phases of our development process for each of the two case studies and describe the two resulting functional prototypes. At the end of each of these sections, we outline what was learned in that phase, and how the method was modified for the second case study based on the experiences with the first one. Section 10 summarizes and discusses the lessons learned for the different phases of the method, and for the application of the method as a whole. Section 11 concludes and outlines further work.

2. RELATED WORK

Mobile and wearable computer devices and applications are being developed for a broad variety of use areas, and recent research has devoted much attention to investigating how in particular distributed mobile workers can benefit from mobile computer systems. This includes work settings where people are concerned with computerized information and processes of critical importance remote from their current location. Early examples include distributed process control and error diagnosing in wastewater treatment plants (Nielsen and Søndergaard 2000), and the use of mobile multimedia for telemedicine and early diagnosing in emergency ambulance services (van den Anker and Lichtveld, 2000). More recent examples include logistic vehicle management at automobile terminals (Rügge et al. 2009), vessel control within the fishing industry (Lumsden et al. 2008), and mobile technologies in hospital settings (Tang and Carpendale 2008, Skov and Høegh 2006, Bardram and Hansen 2004). In order to avoid mistakes and accidents in such safety critical work domains, it is important to understand the state of the systems being operated. This is a classic challenge within human-computer interaction (HCI) and Software Engineering (SE) in response to which Rasmussen (1983, 1986) suggests that computer interfaces should be designed to improve operators' reasoning about the *domain of operation*, and Norman (1990) suggest that systems should support *human interaction* rather than total system automation. These are good, general, recommendations – but in order to achieve this, it is important that system developers have a great deal of rich, detailed, and structured understanding of the use domain, and that the structures, relationships and processes of the use domain are clearly reflected in the core of resulting system designs.

Analysis, design, and prototyping methods are general means for supporting development of user interfaces and software systems, and a lot of attention has been given to their development and refinement for traditional, stationary, computer technologies.

For mobile systems, however, although it has been argued that these necessitate re-thinking of established systems development methods (Krogstie et al. 2004), generally very little has been published on the topic. Instead the field of mobile computing is characterized by research describing specific systems, their technical implementation, their context, and their use (Kjeldskov 2012, Hosbond and Nielsen 2005, Kjeldskov and Graham 2003). Exceptions include Sharples et al. (2002) and Mikkonen et al. (2002) who outline a number of differences from the development of traditional software within the area of HCI, and (Hosbond 2005) who presents a case study of development practice in seven companies within the mobile industry. Given the inherently "situated" characteristics of mobile systems use contexts, an obvious candidate approach for informing technology development is ethnography.

Ethnography in HCI is a methodology originating from the social sciences and used to provide descriptions of human activities in a particular context through studies in their fullest possible context, such as observational field studies and contextual interviews. Although there is currently a trend towards returning ethnography in HCI to its anthropological origins (Crabtree et al. 2009) and focus on the broader study of culture, it is the use of ethnography for informing systems design that we are interested in here. Like Crabtree et al. (2009) we believe that this is done best through structured in-depth analysis rather than through literary accounts based on selective observation and reporting.

In reviewing the literature from the last half a decade it is clear that ethnography, in various forms, has increasingly been applied as a research methodology within the area of mobile human-computer interaction since 2003 (Kjeldskov 2012). In our opinion this is a positive trend for the research field as it indicates a shift in perspective from a singular focus on technology to a more holistic view on technology-in-use. However, one of the problems with ethnography for informing design and development of computer systems, mobile or not, is that it generates primarily descriptive findings and knowledge with such contextual richness that it can be hard to transfer into specific system design. Looking at recent literature, which reports only very few accounts of any kinds of field work directly informing design and implementation of mobile systems, this still appears to be a challenge (Kjeldskov 2012).

There has been a lot of research into bridging the gap between ethnography and software engineering over the last decade (Paay et al. 2009). The essence of this challenge is that it can be difficult to transfer findings and knowledge from ethnographic studies to system design and implementation (Hughes et al. 1997). This is partly caused by a fundamental difference in thinking and working within the social sciences and engineering. As pointed out by Viller and Sommerville (1999), ethnography deals in "the particular" while software engineering deals in "the abstract". Extending this further ethnographers work with rich and concrete descriptions and understandings, while software engineers work with formal models and abstractions (Paay et al. 2009). In respect to their outputs, "Ethnographers avoid judgements; designers make them" (Paay 2008).

Hence, HCI researchers have struggled with the challenge of making these two communities of practice function well together in the creation of software systems that

are both grounded in contextual richness and abstract models. From a team composition perspective, approaches have been explored that aim to integrate social analyses better into design processes through creation of multi-disciplinary teams comprising both ethnographers and software engineers (Diggins and Tolmie 2003, Hughes et al. 1995). From a data representation perspective, approaches have been explored that present outcomes from ethnographic field studies in software engineering terms, such as UML notation (Viller and Sommerville, 1999). However, bridging the gap between ethnography and software development remains a current research challenge (Schraefel et al., 2004; Walenstein, 2003; Wiltshire, 2003), as pointed out in the overview of related literature provided by Paay et al. (2009). Motivating further research within this topic, there are several examples where ethnographically based methods have demonstrated usefulness in the requirements gathering phase of software development projects, for example Crabtree (2004), Viller and Sommerville (2000), Simonsen and Kensing (1998), and Hughes et al. (1994).

3. AN EMPIRICAL STUDY OF BRIDGING THE GAP

Between 2001 and 2006 we conducted two related case studies with the aim of developing mobile information and communication systems for supporting distributed work activities within industrial process control. The second case study built on the experiences from the first one in terms of the system developed and the process followed. Both case studies explored the development and use of mobile computer systems devices for making communication persistent and providing formalized representations of a shared, safety-critical, work domain. Both case studies followed the same overall process of combining ethnography object-oriented analysis and design for obtaining contextual richness as well as abstract models as foundations for the design of functional prototype systems. The central activities of the process, and how they influenced each other, are illustrated in figure 1.

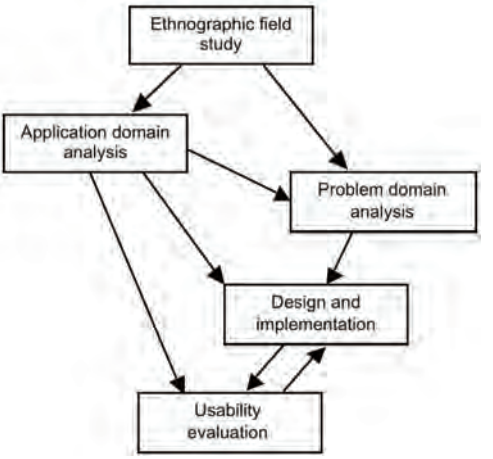

Figure 1. The five major activities in the two development processes

The development processes involved 1) ethnographic field studies, 2) application domain analysis, 3) problem domain analysis, 4) design and implementation of a functional

prototype, and 5) usability evaluation of the system in use. The ethnographic field study activities involved observational studies and contextual interviews (Beyer and Holtzblatt 1998). The object-oriented analysis and design activities followed the method described by Mathiassen et al. (2000) with additional input from Nunes and Cunha (2001a, 2001b) and Dayton et al. (1998). The usablity evalutions followed the methods described by Kjeldskov and Stage (2004) and Kjeldskov and Skov (2007). In the following sections, we describe each of these five steps for each of the two case studies. We describe the two case studies in parallel, structured by the five steps of the development process in order to show their similarities, how the second study built on the first, and how it was modified (and improved) on the basis of lessons learned.

4. ETHNOGRAPHIC FIELD STUDIES

The starting point for the two development processes was an ethnographic field study of work activities in the specific domain of industrial process control in focus. These are described below.

4.1. Case study 1: the container ship

The first case study emerged from a larger study into work activities in the maritime domain involving computerized process control and information systems on board Maersk-Sealand container ships. Maersk-Sealand operates some of the world's largest container ships of sizes equivalent to 3½ soccer fields (figure 2). The operation of such a ship is safety-critical. Especially when manoeuvring inside a harbour, erroneous actions may result in the ship running aground, into the quay, or colliding with other ships. In either case, such collisions would cause serious material damage, potentially severe injuries for personnel, and possible loss of human life.

Figure 2. Sine Maersk at the terminal. Numbers indicate positions of cooperating teams

The field studies were conducted over a period of several months in 2000 and 2001 and involved researchers taking part in a number of voyages on board large Maersk-Sealand container ships and other ships. During these voyages, data consisting of high quality video and audio recordings and written notes regarding work activities, communication and technology use during operation of the ships was gathered through observations and interviews in situ.

Apart from informing new interface design for existing maritime instruments (Andersen and May 2001), a number of work activities were identified in which the use of mobile computer systems could be useful. These included diagnostic and maintenance

work in the engine room, surveying the condition of reefers during voyages, locating personnel in case of accidents, and supporting various distributed collaborative work activities. Of particular interest to us, the field studies identified some general limitations in means of communication and coordination in relation to the operation of "letting go the mooring lines" before departing from harbour. This particular operation was therefore chosen for further investigation, leading to the design and development of the "Maritime Communicator".

4.2. Case study 2: the power plant

The second case study grew out of the first study and an interest in our work on mobile computing from a regional power plant (figure 3). The Northern Jutland power plant is a large coal-based power plant situated on the outskirts of Aalborg, Denmark, that produces central heating and electricity to the region. The operation of the power plant is safety-critical because it involves the operation of large industrial machinery and there are particular fire dangers. The collaboration with the Northern Jutland power plant allowed us to further explore some of the design ideas embodied in the Maritime Communicator, and the methodological approach used to develop it, but in a different domain. This led to the design and development of the "Power Plant Communicator".

Figure 3. The Northern Jutland power plant

For the field studies we took the same approach as with the container ships. We wanted to gather rich empirical data about the use domain before engaging in design, which required spending long periods of time in the field – quite literally getting our hands dirty. After initial enquiries, it was suggested by our collaborators at the power plant that we focus on work activities in the fuel department, as the operation of this part of the plant is essential for ensuring continuous production of energy. As the fuel department also involves workers distributed over a large physical area, relying on centralized computerized controls and coordination based on spoken communication in a noisy environment, this was comparable to the operation of "letting go the lines" on board the container ships.

The field studies consisted of a series of visits to the fuel department of the power plant interviewing the workers in situ and observing their work areas and tasks. This took place over a period of two months. The visits were documented with photographs of work places and artefacts, and through video recordings of the way key tasks were carried out. This provided a rich understanding of the application domain and detailed insight into the communication problems experienced during the work.

5. APPLICATION DOMAIN ANALYSIS

One of the key characteristics of the OOA&D method devised by Mathiassen et al. (2000) is the distinction between *problem* and *application* domain in the analysis phase. Mathiassen et al. (2000) defines the problem domain as "the part of a context that is administrated, monitored, or controlled by a system". Accordingly the application domain is defined as "an organization that administrates, monitors, or controls a problem domain". This distinction is introduced in order to guide the focus of the analysis activity towards the broader use context (application domain) and the specific part of this context that the system is going to be concerned with (problem domain) respectively. The sequence of the application and problem domain analyses is not prescribed but should be informed by the specific system development case and process at hand. When building on top of an ethnographic study, starting with the application domain analysis facilitates a gradual narrowing of focus from the broader context to the specific system, and was found most suitable.

The central principles of the application domain analysis are to describe the current situation in terms of processes, structures, and problems, and to identify actors and use cases. These are described for both case studies below.

5.1. Case study 1: the container ship

When a container ship is ready for departure, the first step in leaving the harbour is "letting go the lines" that holds it in a fixed position (figure 4) and heaving these lines onboard the ship.

Figure 4. The aft mooring of Sally Maersk

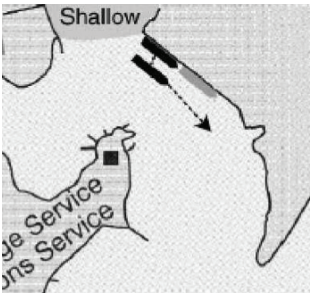

Figure 5. Sally Maersk leaving Felixstowe harbour

While this might seem a trivial procedure, it is in fact both complex and dangerous. As the physical space inside harbours is quite restricted and means for precisely manoeuvring large ships are limited, all lines cannot simply be released simultaneously. Furthermore, when a line is let go, it will remain in the water for a period of time during which no means of propulsion is available due to the risk of lines getting sucked under water and wrapped around the propeller or into the thrusters. Instead the ship can be pulled ahead or astern by means of operating the winches on the remaining lines. Due to these premises, mooring lines are released sequentially in accordance to the need for manoeuvring in a given situation, bringing the ship out side wards and then going ahead when clear of the quay and other ships nearby (illustrated in figure 5).

Due to the huge size of container ships, the work tasks involved when letting go the lines are distributed among a number of co-workers located at strategic positions (see figure 2). On the bridge (1) chief officers control the rudder, propeller and thrusters; and fore and aft (2 and 3) the first and second officers control the winches for heaving in the lines. Ashore, two teams of assistants lift the lines off the bollards. To insure the safety of the operation, individual work tasks are carefully coordinated and carried out under strict command of the captain. Communication between co-workers in the maritime domain is primarily spoken. While people on the bridge can see and hear each other directly, personnel on deck are, however, out of direct visual and audio contact, and communicate via walkie-talkies.

In order to carry out the operation of letting go the lines in a safe manner, the captain needs overview and control over the propulsion, direction and mooring of the ship. While information about the rudder, propeller and thrusters are available on dedicated instruments on the bridge no information is available about mooring. This only exists as a mental model in the head of the captain. As this mental model is highly sensitive to errors or misunderstandings in the ongoing communication between bridge and deck, and since disparity between the captain's mental model and the real world may cause wrong decisions to be made, considerable resources are spent on establishing and maintaining common ground (Clark and Schaefer, 1989) among the distributed co-workers.

Observed communication problems

Supporting operations on board the container ship, well-established rules and procedures exist for oral communication such as confirming status reports and commands by repeating them back to their sender. To a large extend these procedures work very well. However, from the observations and interviews a number of key limitations emerged related to the use of spoken communication for coordination of collaborative work activities: Sound quality is often poor, communication is not persistent but is time consuming and suffers from bottlenecks due to multiple parallel treads.

Overcoming or reducing (at least some of) these limitations served as an overall motivation for the design of the Maritime Communicator. Inspired by chat applications, newsgroups and Short Messaging Service (SMS) it was our belief that shifting to text-based communication on mobile devices would provide an asynchronous channel making communication persistent and requiring low cognitive overhead (Churchill and Bly 1999, Popolov et al. 2000).

Communication structures

In order to understand the communication happening while letting go the lines better, video recordings from the bridge of Sally Maersk during multiple instances of manoeuvring inside harbours were transcribed, coded and analyzed.

This was used to derive the use cases involved with coordinating and carrying out the operation in terms of the sequence of commands issued by the captain and the structures of subsequent communication between bridge and deck. Furthermore, a complete set of utterances: commands, confirmations and status reports, necessary for coordinating the whole operation was produced. Analyzing the typical sequences in the transcriptions

of commands issued by the captain also revealed that some commands would always precede others. Also, the possible next commands at any point of the operation could always be deduced. Not surprisingly, this structure was found to correspond to the basics of the "conversation for action" model in speech-act theory (Winograd and Flores, 1986). Hence we realized that if parts of this structure were modelled in the system, the current stage of each step of the operation could be formalized and, for example, represented graphically or integrated with other computer-based data. Also, the potential next stages of any step of the operation could be identified, and possible utterances by any of the communicating actors be deduced, and possibly prioritized.

5.2. Case study 2: the power plant

The power plant is divided into two separate production plants (locations #7 in figure 6). The fuel for the two plants is supplied from a large central coal storage area (locations #2 and #3).

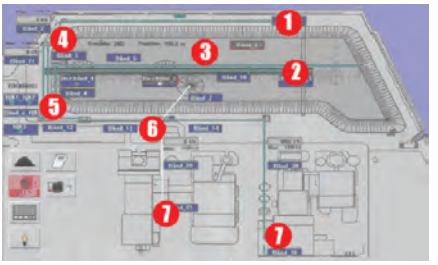

Figure 6. Key locations of the fuel department

Figure 7. Coal storage area

The fuel department is responsible for delivering the coal used in the two production plants, amounting daily to 5000 tons of coal for each. The employees in the fuel department continuously monitor and control the transportation of coal and must ensure that the correct amount of coal arrives at the correct location, and that the coal has certain properties and quality. In order to ensure this, the coal is filtered and grinded (locations #4 and #5). After the coal is processed, it is transported to the two production plants (locations #7) by means of underground conveyer belts. Another important task for the workers in the fuel department is to prevent the coal from self-combusting in the storage area.

Communication to support coordination

The workers perform a variety of different tasks to ensure that the amount of coal needed is delivered to the two production plants. In order to coordinate the many tasks described above, quick and easy communication is important, and in some cases even essential, in order to carry out the job in a safe and efficient manner. Communication happens via VHF radios, DECT wireless phones, and some times mobile phones. Currently, the control tower (location #6) is the only place where all necessary information is accessible. It is also the place where workers operate and control most of the machinery.

Figure 8. Coordination between workers in the control tower and on the ground using VHF radios and mobile phones

The overall operation of coal transport can be controlled by means of a computerized process control system. However, when a problem occurs that cannot be solved from the control room, for example in the grinder building (location #5), the personnel sent to the site to solve the problem do not have direct access to the control system. Conversely, the specific parts of the individual machinery distributed throughout the plant (for example physical handles on the grinder) can only be operated on site. Consequently, full control of the plant requires communication and coordination between personnel on site and in the control room (figure 8).

Observed communication problems

Although DECT phones, VHF radios, and mobile phones offer flexibility and portability, several problems were reported and observed. Firstly, since the conveyor belts run underground and many machines are located inside solid concrete buildings, radio communication is not always reliable due to lack of signal strength. Secondly, there is typically a deafening noise in the tunnels under the plant and inside the buildings, which makes talking to each other difficult and the use of any kind of mobile device for verbal communication virtually impossible. In summary, the workers experience communication problems related to three issues. One is loss of signal, another is noise, and a third is lack of information access on the ground.

In terms of communication structures, similar sequences and confirmation procedures were observed as on board the container ships. This supported our belief that a text-based communication device might also be of value here. It was, however, observed that due to a larger number of locations and objects (i.e. machinery) a wider vocabulary of nouns was used in the operation of the fuel department than in the operation of letting go the lines. The vocabulary of verbs was, however, similarly small, and the same verbs were used in relation to a lot of different machinery (e.g. start, stop, reverse, assist).

5.3. What did we learn from the two application domain analyses?

The two application domain analyses provided a rich, yet structured, understanding of the use context that we were dealing with. Grounding the analyses in ethnographic field studies meant that a lot of detail was captured, and that our initial design ideas were directly inspired by the use context.

In terms of the application domain analyses there was no notable difference between the two case studies. Both mapped out the overall use context, specific work tasks,

means and procedures of coordination, revealed problems related to the use of spoken communication, and discovered structures in communication.

The application domain analyses provided input for the problem domain analysis phase in the form of focus and data, for the design and implementation phase in the form of system context, and for the usability evaluations in the form of information for recreating realistic use contexts and developing realistic and relevant tasks.

6. PROBLEM DOMAIN ANALYSIS

At this point in the two case studies, we had identified specific work areas of focus, overall division of work, and sequences and structures in communication. As is often the case in projects like these, we had also already begun thinking about design of new technology solutions for the work activities and problems observed. However, rather than moving straight into the design phase, we conducted a second round of analysis as prescribed by Mathiassen et al.'s (2000) OOA&D method. The second round of analysis focused on the problem domain, defined as "the part of the context that is administrated, monitored, or controlled by a system" (Mathiassen et al., 2000). The aim of the problem domain analysis is to support later design and implementation by identifying objects, classes and relations, and providing detailed descriptions of the states that these objects go through. The outcome of the analysis is a description of these objects, classes, structures, and behaviors. The outcomes of the two problem domain analyses are described below, including some of their implications for the design of the resulting prototype systems.

6.1. Case study 1: the container ship

The two major activities of the problem domain analysis for the container ship case study were the modelling of a class diagram for the problem domain (figure 9) and a state chart diagram for the *Let go* class.

Class diagram

Modelling the class diagram was a challenge primarily because we extended the problem domain to include additional work activities related to manoeuvring inside the harbour other than the operation of letting go the lines. This was done to support extending the scope of the Maritime Communicator later without having to change the model.

From the class diagram, we identified a number of issues, which directly informed the design of our prototype system. Firstly, the class diagram illustrated that letting go the lines is one of three similar operations (or tasks) related to manoeuvring inside the harbour. On the basis of this, we found that the Maritime Communicator should have facilities for tailoring an interface supporting each of these specific operations on the basis of a general design for supporting communication and coordination. Thus, general interface elements should be associated to the overall Task class while more specialized interface elements, such as specific graphical representations, should be associated with their appropriate specialization.

Secondly, we found that since the *Commanding officer* class and the *Officer* class aggregate from fundamentally different classes (*Ship* and *Team* respectively), different interfaces for these actors might also be appropriate. Thus the interface for

the commanding officer should possibly include information about the ship while the interface for the officers on deck should include information about the team instead.

Finally the class diagram helped us realize the role of the *Location* class as a mediator between the *Ship* and *Task* classes. Thus knowing the location of a mobile device would enable us to deduce the role of its user and adapt the interface accordingly.

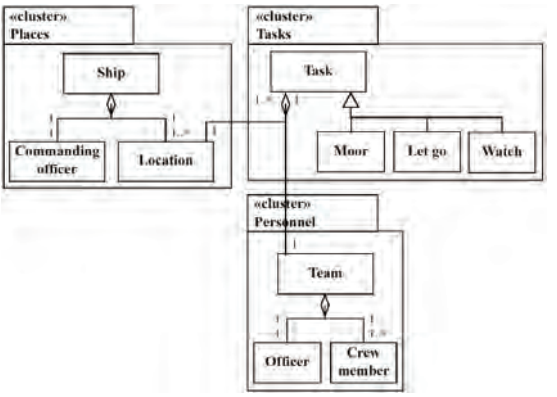

Figure 9. Class diagram for the problem domain

State chart diagram

As the *Let go* class would contain the structure of the operation and communication, a lot of effort was put into modelling its state chart diagram (figure 10). Even though valuable input for this already existed from the application domain analysis, making a precise model was a challenge. Firstly, a number of variations in the sequence of the operation had to be modelled. Secondly, we had to model some commands as implicitly containing others, depending on the situation. Finally, we had to model that several commands were being executed in parallel, and could have influence on each other. The state chart diagram was created on the basis of the video recordings and transcripts of communication gathered through the field studies.

The state chart diagram for the Let go class provided a detailed view of the operation of letting go the lines. First of all, it provided both the details and abstraction needed to actually implement the idea of partially automating sequence and communication that emerged from the application domain analysis. Secondly, it showed that each command goes through three overall temporal stages of being imminent, executing, and ended. While in some situations ended commands may be important, in other situations only executing commands are vital. From this finding, we were later able to divide the interface into three corresponding areas reflecting enabling a very simple differentiation of priority.

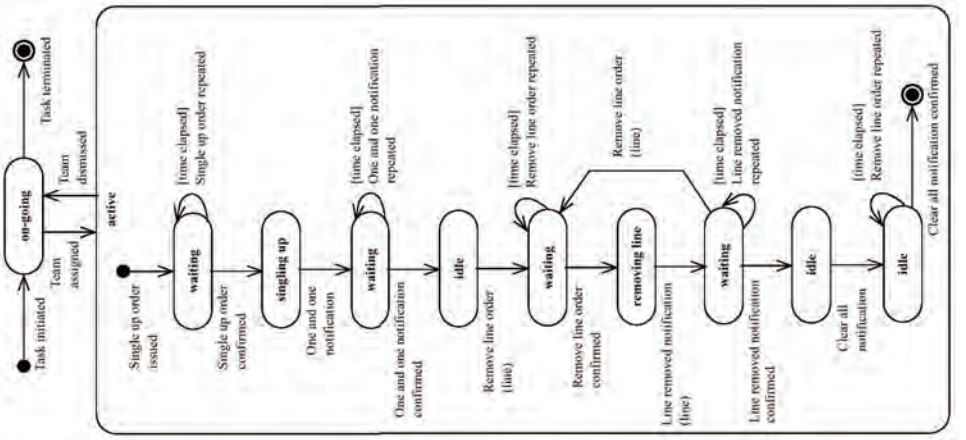

Figure 10. State chart diagram for the Let go class

6.2. Case study 2: the power plant

In the power plant case study, we modelled the problem domain in a class diagram that captured the most central objects in the use context of a mobile information and communication system for workers in the fuel department. Informing the development of the class diagram, we also did user profiling in order to describe in more detail the workers whose activities needed to be supported by the system. The outcome of this was the identification of the two primary roles of *controller* and *field worker.*

Providing additional detail for the subsequent design and implementation phase, the problem domain analysis was extended with additional modelling techniques from the related Wisdom method (Nunes and Cunha 2001a, 2001b). This prescribed the identification of, for example, essential tasks and associated state chart diagrams. Modelling these essential tasks in state chart diagrams, however, turned out to be more difficult because many tasks at the power plant were only carried out rarely, and not all of them had happened during our ethnographic field study. In order to overcome this problem, we decided to intervene and stage a series of situations in which the workers *acted-out* (Howard et al. 2002) work activities, communication and coordination in real world settings. This allowed us to observe these rare situations, adding to the ethnographic data. On the basis of the joint body of data, we identified nine essential tasks that the system needed to support. For each of these tasks, a state chart diagram capturing the flow of the task was produced (see figure 11a).

Motivated by the lessons learned from the container ship case study, where the usability evaluation of the functional prototype had later revealed a problem with one of the state chart models from the problem domain analysis, we wanted to validate these models with the users. As we were also interested in some early feedback on a number of design ideas spawned from our analysis, the model validation was integrated into a paper prototype evaluation (Snyder, 2003). The paper prototype consisted of a series of screens drawn on paper, which could be placed on top of a PDA (figure 11b). It was evaluated with real users on site at the fuel department through a series of sessions where a number of workers acted-out their use of the prototype. This provided feedback

on both the envisioned functionality and the prototype's structural design, enabling us to evaluate the applicability of our overall design ideas, as well as the underlying models. The evaluation resulted in some modifications to the essential task models, and yielded a number of useful new design ideas. The final class diagram included 9 classes, and the functional list for the system comprised 22 functions.

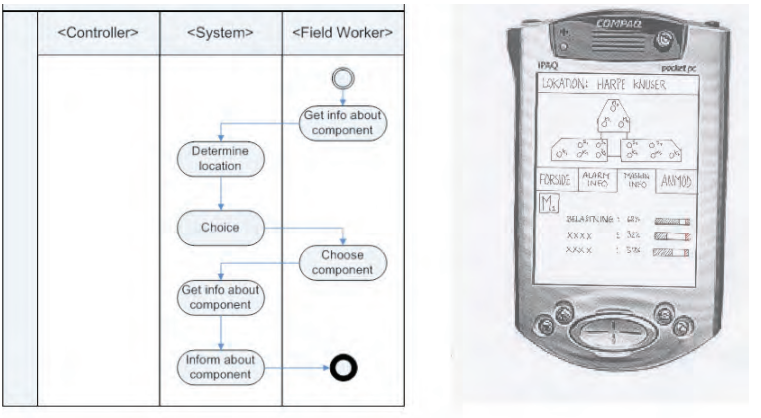

Figure 11. State chart diagram for getting information about a component (a) and the corresponding user interface of the first paper prototype (b)

6.3. What did we learn from the two problem domain analyses?

The two problem domain analyses reduced the complexity of information from the application domain analyses to a series of abstract models, while still preserving the essence of contextual grounding obtained through the ethnographic field study. As described above, creating object-oriented models based on our ethnographic data and application domain analysis not only formalized important aspects of the immediate system context but also generated additional insight into this context than had been gained from the previous phases alone. We learned more about the specific division of labour in the two work domains, the complexities of tasks, and the structures of operations and communication. This additional insight was essential for the subsequent design of our mobile prototype systems.

The two problem domain analyses differed in some specific aspects. While the overall focus and purpose was the same, the second case study deployed additional techniques from the Wisdom method (Nunes and Cunha, 2001a; 2001b) prompting the development of additional models, for example of essential tasks. This was done to explore the added value of these models when working with ethnographic data and mobile human-computer interaction design. As a result of this addition, we were able to see that some information was missing from our ethnographic field studies, and go back and gather additional data at a relatively early stage of the development process.

7. DESIGN AND IMPLEMENTATION

The models created in the problem domain analysis formed the basis for the design and implementation phases of the two case studies.

7.1. Case study 1: the container ship

Following the analysis phases, a team consisting of the authors of this article engaged in the design and implementation of the Maritime Communicator. The design and implementation process consisted of four iterations each producing design documents on different levels of abstraction (figure 12). Apart from being directly informed by the application and problem domain analyses, the designs produced were inspired by related literature on text-based communication such as Popolov et al. (2000), Smith et al. (2000), Smith and Fiore (2001) and related systems such as chat, newsgroups and the Short Messaging Service (SMS).

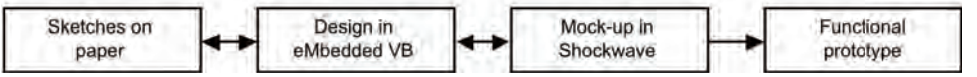

Figure 12. The four stages of our 1st design and implementation phase

Sketches on paper

First, a series of paper based sketches of possible interface designs were produced on the basis of the analysis and inspired by the use of multi-threaded communication and pre-defined messages in other systems. These paper mockups facilitated fundamental discussions of the basic interface design and led to an overall concept providing: 1) a graphical representation of the ship and its mooring lines; 2) a transcription of the communication sorted by objects of reference; and 3) facilitating communication through pre-defined textual commands selected from lists.

Design in eMbedded Visual Basic

On the basis of the paper sketches, detailed design was produced in Microsoft eMbedded Visual Basic. This forced the design team to work within the limitations of the target platform in terms of screen size and graphical interface elements supported in the development toolkit. Consequently, a number of shortcomings arose related to the specific division of screen real estate and the desired level of detail of graphical representations. While most of the subsequent refinements of the design were done directly in Visual Basic, larger design issues such as how to support the textual representation of multiple parallel threads of commands, in what turned out to be a *very* limited graphical space, temporarily forced the design team back to pen and paper.

Mock-up in Shockwave

Screen exports from eMbedded Visual Basic (modified in Adobe Photoshop) were used to produce a Shockwave-based mock-up in Macromedia Director showing a possible sequence of communication. Adding life to the Visual Basic-based design in this "quick-and-dirty" fashion facilitated further discussions within the development team and resulted in minor design modifications before doing any real programming. For example, it was decided that the user should not be prompted for confirmations through pop-up screens (as these would temporarily cover vital information). Instead, confirmations were included in the existing list of possible utterances.

Functional prototype
After a final design had been agreed upon, this was implemented in a functional prototype using Microsoft eMbedded Visual Basic. First, the underlying data structure of the system was implemented in accordance with the class diagram and state chart diagrams produced in the object-oriented analysis. Following this, the user interface was implemented in accordance to the final design. Once the user interface and interaction worked properly we implemented network interfaces and protocols for distributing the system on multiple devices. Implementation amounted to a total of 15 person-days.

7.2. Case study 2: the power plant

The design and implementation phase for the Power Plant Communicator followed a slightly different process (figure 13). System design and implementation was delegated to a group of four developers under the management of the authors, and the design of the Maritime Communicator, along with evaluation data, was provided as a starting point. Instead of design sketching we included an additional object-oriented modelling activity based on the Bridge method (Dayton et al. 1998), and used this activity to direct our specific user interface design.

Figure 13. The four stages of our 2nd design and implementation phase

User interface modelling
As indicated by its name, the Bridge method *bridges* between problem domain analysis and user interface design. This is done through the development of three related models of the user interface on different levels of abstraction: 1) *interaction model,* 2) *presentation model,* and 3) *dialogue model.*

The interaction model describes the interaction spaces and tasks that the system should support. An interaction space is an abstract user interface element, which still has no specific graphical properties. A task is an activity that is carried out by a user employing one or more interaction spaces (figure 14). The left column of the interaction model contains the interaction spaces. The second column contains the tasks, and the three columns on the right represent internal elements of the system.

The presentation model describes each interaction space in more detail, specifying on an abstract level what each individual screen should contain in terms of output elements, input elements and possible user actions but without saying anything concrete about what these elements should look like (figure 15). The attributes of the presentation model classes are defined on the basis of the class diagram for the problem domain. The operations are defined by distributing the function list developed in the problem domain analysis between the individual presentation model classes.

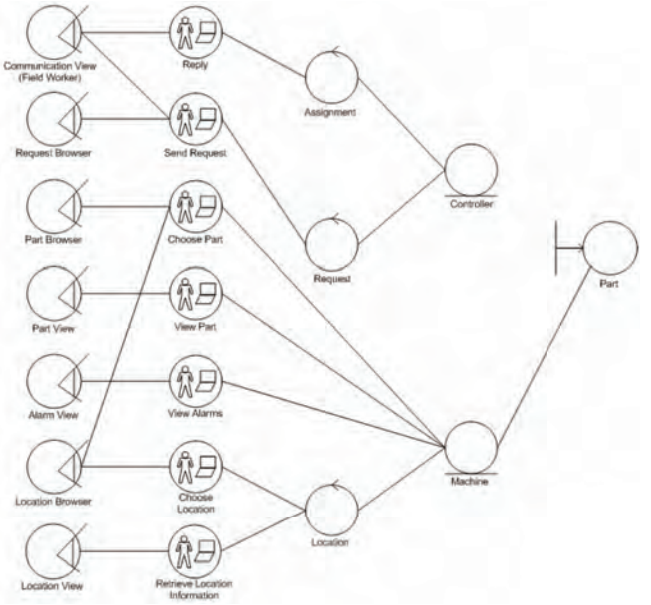

Figure 14. Interaction model for the Power Plant Communicator

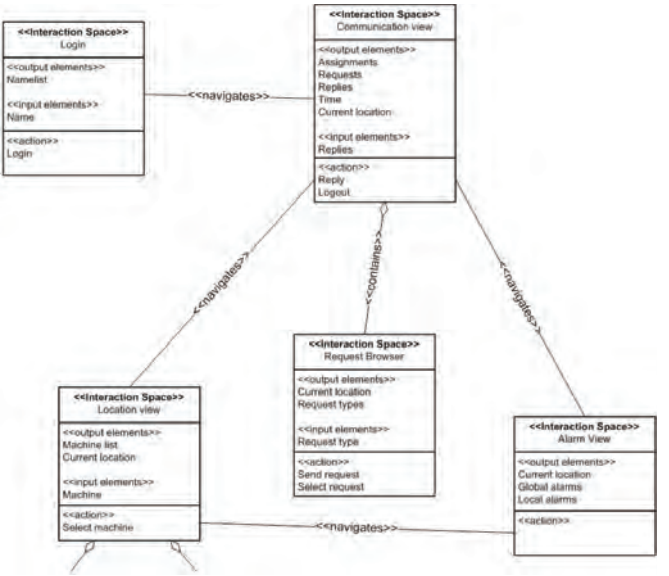

Figure 15. Part of the presentation model for the Power Plant Communicator

User interface design

The first step of the user interface design activity was to transform the interaction, presentation and dialogue models into concrete design. Informing this process, the three models from the Bridge method described above provided important input on different levels. The interaction model provided input on the overall structure and relationship between individual screens. The presentation model provided a detailed list of elements

that we had to include on each specific screen. The dialogue model described the sequence by which the workers would typically interact with the screens.

As illustrated in figure 16, knowing what information and functionality to provide, and when, proved to be highly valuable information in order to maximize the use of the small screen real estate of the target platform. In order to reduce complexity, figure 16 only depicts some of the connections between interaction spaces and screen design.

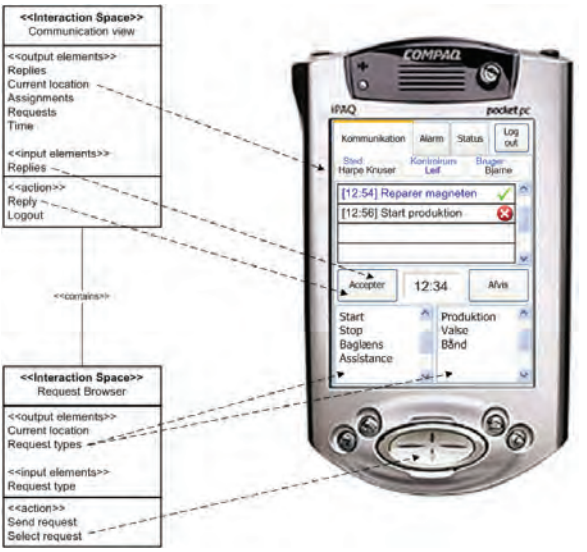

Figure 16. Mapping of presentation model classes to user interface design

Paper Prototype

The user interface design developed on the basis of the interaction, presentation and dialogue models was transformed into a second paper prototype with a high level of fidelity (figure 16 right). The paper prototype was then evaluated in situ at the power plant with prospective users acting-out a series of realistic use scenarios. Observations from the paper prototype evaluations led to refinements of the user interface design.

Functional Prototype

Following the paper prototype evaluations, a functional prototype that matched the final design specifications was implemented in C# using Microsoft Visual Studio .Net 2003 Professional and the .Net Compact Framework. The implementation activity amounted to a total of 20 person-days.

7.3. What did we learn from the two design and implementation processes?

While the two implementation activities were very similar in process and the amount of time spent, the design activities differed notably from case study 1 to case study 2. The differences reflect that the design activity was more exploratory in nature in the first case study and more structured in the second one. Both processes have their strengths and weaknesses and are applicable depending on the nature of the specific project. The design process for the Maritime Communicator represents an iterative approach where design is carried out with an increasing level of detail using different means of expression

such as paper, interface toolkits, and mock-ups. In this approach, the diagrams produced in the problem domain analysis were important for reference, but design was very much driven by creativity. The design process of the Power Plant Communicator, on the other hand, represents a more structured approach where the outcomes from initial analyses are directly elaborated on in the form of additional models defining abstract properties of the user interface. The "creative" part of the design phase is therefore postponed for longer but in effect informed more directly by ethnographic field study through the models developed. In our experience, the additional object-oriented models focussing explicitly on the user interface helped in keeping the design of the Power Plant Communicator grounded in our field data. In particular, we found that the Interaction Space models provided structured input into the design of each screen of the system without prescribing their look and feel in a way that impeded creativity.

The second major difference between the two design phases was that case study 2 involved user feedback on a paper prototype by subsequent field visits to the context of use prior to implementation. Again, this helped us maintain the grounding of our design process in the initial ethnographic field study to a stronger degree than in case study 1.

8. FUNCTIONAL PROTOTYPES

In this section we describe the two functional mobile device prototypes resulting from the field study, analysis, design, and implementation processes described above: the Maritime Communicator and the Power Plant Communicator. The prototype systems are not the contribution of this article but serve as illustrations of outcome. The two systems are described in detail in (Kjeldskov and Stage 2006) and (Kjeldskov et al. 2006).

8.1. The Maritime Communicator

The Handheld Communicator was targeted at PDAs running the Microsoft PocketPC operating system such as the industrial grade Symbol PPT8800 series (figure 17). Apart from a touch screen, such industrial devices support interaction by means of large rubber buttons located below the display and suitable for one-handed interaction. Due to the potentially harsh conditions of use, in which pen-based interaction might be problematic, all interaction took place through these buttons.

The system setup consisted of three PDAs connected through a wireless network. One device was intended for the captain on the bridge while the other two were for the 1st and 2nd officers on the fore and aft deck respectively.

Overall Design

The Maritime Communicator explores the ideas described in section 5 replacing verbal communication with an exchange of predefined text messages grouped by objects and the state of tasks, and providing an updated representation of the shared work domain.

Figure 17 shows the user interface of the Handheld Communicator for the captain. At the bottom of the screen there is a list of unexecuted commands and confirmations. The order of the list corresponds to the standard sequence of the overall operation, and possible utterances only appear when appropriate in relation to the state of the task. By default, the most likely next step is highlighted (based on the state chart diagrams).

Figure 17. The Maritime Communicator on a Symbol PPT8000

The most important element of the interface is the list of "ongoing tasks". When a command is executed, it appears on this list along with a counter displaying the time passed since it appeared. When a command is confirmed the timer is substituted by the text "[ok]" followed by a description of the current activity (e.g. "Singling up..."). When a task is reported completed, a short statement (e.g. "1 and 1 fore") substitutes the description of activity and the captain is prompted for confirmation. When the captain confirms the completion of a task, the communication thread is moved to the "history" list. When the history list is full, it scrolls the oldest commands and statements out of sight. At the top of the screen a simple pictogram displays the current state of the operation for quick reference: the lines still attached to the quay and the current status of fore and aft.

On deck, the interface for the officers is very similar to that on the bridge thus providing a view on the present status of the mooring and a list of all past and ongoing communication among the distributed co-workers. The main difference is the list of available commands and utterances, which is filtered on the basis of their location and task, and the indications under "ongoing tasks" of commands with responses pending.

Implementation

The application running on the captain's device worked as a server containing a formalized representation of the communication pattern of the task. The devices on deck logged on to this server and identified their physical location. During operation, function calls and unique command identifiers were exchanged over the wireless network. All network traffic was broadcast but processed and represented differently on each device in accordance to their physical location (bridge, fore or aft).

8.2. Case study 2: the power plant

Like the Maritime Communicator, the Power Plant Communicator was targeted at industrial grade PDAs running the Microsoft PocketPC operating system. Interaction was facilitated by the device's function keys and through finger-based input on the touch screen. In addition to the handheld terminals used by the workers moving around the plant, a desktop PC interface was designed for use in the control tower.

Overall Design

The Power Plant Communicator provides mobile distributed workers with access to information in the central computer system about the general status of the plant and about the specific machinery within their proximity. It also gives them a simple text-based communication channel for coordinating certain work activities. The system is divided into three overall screens with a number of associated sub-screens: 1) Communication screen, 2) Alarm screen, and 3) Status screen. At the top of the display, the system indicates who is logged in, where the user is located and what time it is. This information is important for the field workers because it gives them a frame of reference for interpreting the information and functionality provided by the system.

The communication screen

The communication screen (figure 18) provides workers with a text-based communication channel (inspired by the Maritime Communicator). Using the two lists next to each other above the panes the user can compose a message by combining a verb with a noun, for example "stop production". Above these two lists there are three buttons for sending the composed message, or for sending a standard reply that you Accept (Accepter) or Reject (Afvis) a particular request. To avoid pressing the wrong button by mistake, the buttons for accepting or rejecting are placed furthest apart. Above these three buttons the ongoing conversation is displayed on a list. The list is divided into a series of conversation threads, grouping communication about the same object or task together. To make a clear difference between requests and confirmations, the latter are indented and have their first word (for example ACCEPT or REJECT) in capital letters. To add a new message to a thread the user selects an utterance on the list, for example "Check Harper/Knuser 2, and sends a response.

Figure 18. Communication screen

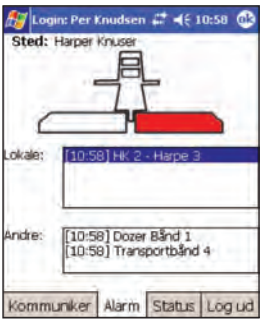

Figure 19. Alarm screen

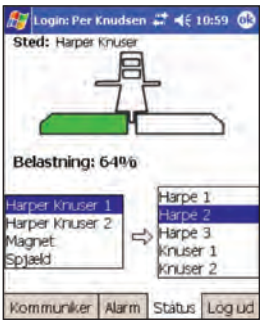

Figure 20. Status screen

A main difference in this design compared to the Maritime Communicator is that messages are composed from two lists rather than one. This design emerged from the

object-oriented models revealing that the number of possible utterances was very large, but that they were all composed from a common set of verbs and a set of nouns related to the users' location. Because the system knows where the workers are physically located at the power plant, it can deduce which machinery they are most likely to be communicating about (generating the list of nouns). Knowing about the functionality of the machinery the system can deduce what actions the user can request (generating the list of verbs).

The alarm screen

The alarm screen (figure 19) alerts the workers if something is wrong at the power plant and provides them with the available details about the problem. If an alarm is associated with the users location, detailed information is displayed immediately. The alarm screen contains a graphical representation of the machinery in question, with the area of the problem highlighted in red. Below the graphical representation, there are two lists displaying alarms at the users current location and other alarms along the production line. These lists were included because our models showed that problems along the production line often cause other problems to happen, requiring co-located workers to start coordinating a shared strategy. Using these lists, the workers can get an overview of the cause and/or effects of a specific problem, thus assisting them in assessing its criticality. Each alarm has a timestamp that enables the workers to determine their sequence and current relevance.

The status screen

The status screen (figure 20) provides workers with access to information about machinery in the production line within their close physical proximity. Below the graphical representation, the users can choose which of the machines within proximity they want to work with (the list on the left), and what specific part of it they want to access information about (the list on the right). The screen can also function as a remote control to some machines basic operations such as start, stop and reverse. The status screen looks similar to the alarm screen in many ways. At the top of the screen, there is a graphical representation of the machine being accessed, with the specific part chosen being highlighted. If the chosen part of the machine is functioning or the load on the part is at a normal level, it is highlighted in green. If the load climbs towards a critical level, the colour changes to orange. If reaching a critical level, the colour changes to red and an alarm is activated. These states were revealed through our models.

Implementation

The technical implementation of the Power Plant Communicator was similar to the Maritime Communicator. The computer in the control tower (a desktop PC) worked as a server containing a formalized representation of the power plant and typical work activities. The handheld terminals logged on to this server and identified their physical location, following which an appropriate interface was displayed on them. During use, function calls and commands were exchanged over the network, using handshake to confirm delivery, thus eliminating commands being "lost in the air". All network traffic was broadcast but processed and represented differently on each device in respect to their location.

9. EVALUATIONS AND USER FEEDBACK

The final phase of our two case studies was to evaluate the usability of the produced prototype systems. In the context of this article the evaluations below serve as validations of the outcome of the development processes as well as illustrations of different approaches to "closing the circle" by going back to the domains where our ethnographic field studies were originally conducted. Due to the nature of the two use domains, both evaluations were challenging to carry out in a realistic, but safe, manner. This challenge was addressed in two different ways: by carrying out the evaluation in a high-fidelity ship simulator and by acting out use scenarios at the power plant.

9.1. Case study 1: the container ship

The Maritime Communicator was evaluated in a state-of-the-art ship simulator at Svendborg International Maritime Academy in Denmark (Kjeldskov and Skov 2007). The evaluation involved three teams of two experienced maritime officers as test subjects. The officers were given the task of letting go the lines and departing from harbour using the Maritime Communicator for communication and coordination. One subject user acted as captain on the bridge (figure 21) while the other acted as 1st officer on the fore deck in a neighbouring room.

The ship simulator was set up to imitate the operation of a large ship in challenging weather and traffic conditions. The scenario was developed in collaboration with the simulator division of Svendborg International Maritime Academy, and corresponded to a real world situation observed during our field studies described above (see figure 5).

During the evaluation the captain had to consider all aspects of manoeuvring the ship. This included controlling the rudder, propellers and thrusters as well as communicating with personnel on the ship, harbour traffic control and taking into consideration the movements of other ships. The 1st officer on deck verbally forwarded commands to his team of assistants on the quay and manning the winches and reported progress back to the captain. The team of assistants were a part of the digital simulation.

Figure 21. Evaluation of the Maritime Communicator in a ship simulator

During the evaluation, the users were asked to think-aloud, explaining their experience of and interaction with the prototype. Two evaluators located on the bridge and on the deck respectively observed the users and asked questions for clarification. Following each evaluation session, a group interview of 10-15 minutes was carried out. The

evaluation sessions were recorded on digital video from four camera sources and audio capturing close-up views of the handheld devices and overall views of the use context.

Highlights from evaluation

The evaluation of the Maritime Communicator in the ship simulator provided rich data on the usability of the design. First of all, the user study showed that the prototype could actually replace the majority of spoken communication between the captain and officers. Also, the users expressed that the text-based interface gave them a simple channel of communication in which they could easily monitor the ongoing communication and progress of the operation. As a supplement to this, some officers on deck expressed a wish for having commands read out by a synthetic voice as an option when they were busy with their hands elsewhere. Generally, the users learned what to do and what feedback to expect within the completion of one or two threads of communication and reported that the design was very intuitive to use. The differentiation between commands appeared straightforward as did the grouping and progress of ongoing threads. The graphical representation of the ship was highly appreciated for overview, as this was not currently provided.

Apart from the positive feedback, the user study also revealed 22 usability problems experienced by the users. First of all, we identified a need for being able to request or report something out of the ordinary, and to correct or withdraw an utterance. This finding indicated that our ethnographic field study had missed situations where there was a need to communicate things out of the ordinary, and consequently this was also missing from our problem domain analysis. This lesson learned led us to modify the analysis procedure in the subsequent Power Plant Communicator case study to involve a validation of these models, facilitated by an initial paper prototype evaluation, after the problem domain analysis, as described earlier.

9.2. Case study 2: the power plant

The Power Plant Communicator was evaluated in situ at the fuel department. The evaluation involved five workers with several years of work experience with this particular plant. The prototype system was used during live operation of the power plant while carrying out a series of typical work tasks. In addition to this, a series of less common work activities were acted-out in situ as we had done with the evaluation of the paper prototypes described earlier.

Figure 22. Field evaluation of the Power Plant Communicator in situ

One researcher managed the evaluation and asked questions for clarification. Another researcher recorded the evaluation on a handheld video camera shifting focus between the workers, the settings, and the screen on the handheld device (figures 22 and 23).

The users were asked to think-aloud, but because of the noise level in some buildings, this did not always work well. In these situations, a post-use interview was conducted outside the building immediately afterwards.

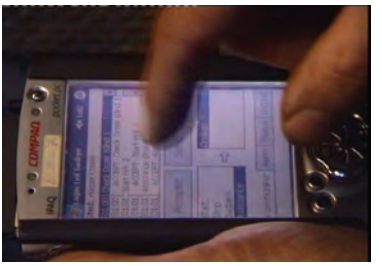

Figure 23. Close-up of the communicator during field evaluation.

Highlights from evaluation

The results of the evaluation showed us that the system was indeed usable and that the workers were satisfied with using it. The users had no problems understanding and adopting the basic functionality of the system. Some compared it to sending SMS messages on their mobile phone. Others compared it to a remote control. In relation to the communication screen, the users reported that they liked to be able to combine text-based messages and spoken communication over the VHF radio. Text-based communication was primarily found useful when noise prevented spoken commands but was also reported very useful in complex situations where they otherwise needed to remember what had been said when and by whom.

Regarding the alarm screen, the users reported that the annotated graphical representation would help them greatly in locating and fixing problems quickly. Some reported that they would like even more detailed graphics and preferably a plant overview as well. On the status screen the users found the simple access to information about machines and control of it within physical proximity compelling and highly useful for their daily operation of the plant. Furthermore, not being able to operate machinery out of proximity was perceived as a significant safety advantage. Apart from the positive observations and feedback the evaluation also revealed 14 usability problems experienced by the users, to be addressed in the next iteration of design and development.

10. SUMMARY AND DISCUSSION

The challenge we set out to respond to by combining ethnography with Mathiassen et al.'s (2000) object-oriented analysis method was that mobile software development requires insight into rich and dynamic use contexts, but that ethnographically based approaches, which are good for studying such contexts, provide data and insights that can be hard to translate into system design. This led us to devise an approach that explicitly combines ethnography with a structured analysis and design approach, enabling us to obtain both contextual richness and abstract models for informing the development of mobile

systems. In the following, we summarize and discuss some of the lessons learned from the two case studies of using this approach presented above.

10.1. Value of application domain analysis

The primary value of applying an object-oriented application domain analysis to the ethnographic field data was that this approach provided a specific focus for the data. Rather than doing an open-ended or grounded type of analysis, which outcomes can be difficult to translate into a system development process, the application domain analysis approach prompted us to specifically address the question of what the system is going to be about, and to generate a set of overall requirements for what we were going to build. Apart from the obvious value of these tangible outcomes, the value of the application domain analysis also lay in the process of doing these analyses as a shared activity within the project teams. This prompted focused discussions about what was observed in the field, and through these discussions we gradually understood more and more the domains we were working with, and were essentially developing systems for. As pointed out above, the outcome of this analysis was able to serve as a common frame of reference for the project teams throughout the rest of the project, representing one of the outcomes from the ethnographic field study.

10.2. Value of problem domain analysis

The two object-oriented problem domain analyses reduced the complexity of information from the application domain analyses to a series of abstract models, while still preserving the essence of contextual grounding obtained through the ethnographic field study. It was at the time of the problem domain analysis that the added value of the object-oriented approach particularly began showing its strengths for the process of system development by prompting the development teams to formalize structures and processes observed in the ethnographies into abstract models. During this process we learned more about the specific division of labour in the two work domains, the complexities of tasks, and the structures of operations and communication than had been obvious from the ethnographies. This additional insight was essential for the subsequent design processes, and the models created were also essential for the later implementation phases. In the power plant case a particular valuable experience with the problem domain analysis was that this activity revealed that some information was missing from our ethnographic field studies, and made us go back and gather this additional field data at a relatively early stage of the development process (as discussed more below). This exemplifies how structured modelling can act as a verification of the scope of the much more unstructured ethnographic study, and illustrates a strength of combining these two approaches in system design.

10.3. Informing the design process

The value of the object-oriented approach for the design process was slightly different for the two case studies. The design process of the Maritime Communicator represented an approach where the diagrams produced in the problem domain analysis were important as structural reference for an iterative and highly creative design activity. By comparison, the design process of the Power Plant Communicator represented an approach where outcomes from the object-oriented analyses were directly elaborated

on through additional abstract modelling before any concrete design activity was carried out. Although this meant that actual interface design was done later in the process, this was at the same time informed more directly by the ethnographic field study. By developing object-oriented models focussing explicitly on the structural design of the user interface, such as Interaction Space models, the design of the Power Plant Communicator remained strongly grounded in data from the ethnography.

10.4. Supporting the implementation process

The value of the object-oriented analysis and design efforts for the implementation of our prototype systems were two-fold. Firstly the structured and iterative approach had informed the creation of a well-specified system and user interface. This minimized effort spent during the implementation phase on essentially doing design, and ensured that focus could be kept on the task of coding. Secondly, and equally importantly, the abstract models developed during the problem domain analysis, and for the power plant case also during the design phase, directly informed the structure of the software programs, and contained all the information required to build the system. This minimized time spent during the implementation phase on translating design specifications into structures that could be coded, and ensured that the code correlated well with the specified design.

10.5. Value of ethnography in mobile HCI

Taking a step back, the ethnographic field studies described in section 4 played an invaluable role in the two system development processes, confirming the potential value of ethnography in mobile HCI as suggested by Kjeldskov and Graham (2003), and illustrated by, for example, Luff and Heath (1998) in their work on mobility in collaboration back in the 1990s. Both of the studies presented in this paper generated rich insights into the use contexts and work activities that would unlikely have been reached otherwise. Firstly, the ethnography on board the container ships generated insights and inspiration that, amongst others, led to the conception of the text-based communicator systems in the first place. In comparison, the ethnography at the power plant was more focused, but confirmed observations from the maritime domain, and led to the identification of different, yet related work activities where similar technology might be applicable, as well as identification of new, unique type of work activities not observed on board the container ships.

Secondly, the two ethnographies generated valuable data for contextually rich application and problem domain analyses. As can be seen in section 5 and 6, these analyses of the general use context, and the specific part of that context that is directly related to the use of the proposed systems, were particular rich in details and strongly grounded in real world observations. This made them extremely useful for the further development process as a frame of reference representing the data from the ethnographies in a tangible and organized form.

Thirdly, the two ethnographies provided insight into the use contexts that was critical for the recreation of realistic test environments for the evaluation of prototype systems. For both cases this included the creation of realistic and relevant tasks. For the container ship case it also included informing the scenario programmed into the ship simulator.

The only limitation of the ethnographic approach experienced related to the issue of missing out of observing a rare event. This was partly due to the inherent naturalistic and non-intrusive nature of the ethnographic methodology, and partly due to the length of time spent in the field. One approach to overcome this issue is, of course, to spend longer time in the field until all possible events have happened and been observed. However, apart from the intrinsic uncertainty about exactly when this criterion has been reached, this is typically not a realistic approach in a software development project. As a response to this, various time-optimized field study techniques such as "rapid ethnography" (Millen 2000) and "rapid contextual design" (Holtzblatt et al. 2005) have emerged, which, amongst others, propose that special effort is made to identify and cover those unusual situations also. The next question here is, of course, *how* to do that? As one possible answer, we experienced that the systematic nature of the objected-oriented analysis provided valuable input for testing the completeness of the ethnographic data gathered, and subsequently guiding the focus of final fieldwork. Consequently, it can be argued that ethnography and object-orientation is best combined iteratively, with going back and forward between field studies and analysis being an explicit part of the approach.

11. CONCLUSIONS AND FURTHER WORK

We have presented two case studies of mobile system development for supporting distributed collaborative work activities within industrial process control. Based on the lessons learned from these two case studies, we have described and discussed how ethnography and object-orientation can be successfully combined for obtaining contextual richness and abstract models for mobile interaction design.

One of the challenges reported is that ethnography generates findings and knowledge with such contextual richness that it can be hard to transfer into system design. By combining ethnography with the software engineering method of object-oriented analysis and design, we have shown how ethnographic field data is a highly valuable source of input for developing object-oriented models by providing contextual richness and that, in turn, objected-oriented analysis is a highly valuable method for working with ethnographic field data in systems development by supporting the creation of abstract models. Combining the two, we have demonstrated a method where the use of ethnographic field studies in system design is supported by the use of a structured analytical approach, and where abstract modelling of systems is informed by rich contextual data. By applying this method, ethnographies are empowered in their capability for informing core system design, and system design is consequently strongly grounded in their use context.

We have applied the proposed methodological approach to two different mobile system development processes over a period of 5 years. In doing this we found that the experienced value of the method generalised from one case study to the other, and we were even able to make some improvements to the specific analytical activities involved. While on the basis of our experiences we believe that the described process has general value for the development of other mobile systems, this should, however, be evaluated through other cases of mobile interaction design applying the method of explicitly combining ethnography and object-oriented analysis and design.

ACKNOWLEDGEMENTS

The authors would like to thank our collaborators at Maersk and the Northern Jutland Power Plant including everyone who participated in the field studies and usability evaluations. We would also like to thank Jeni Paay for valuable discussions of the work and comments on the manuscript. The Power Plant Communicator was developed by Christian Monrad Nielsen, Michael Overgaard, Michael Bach Pedersen and Sigge Stenild, who also collected field data in the second case study. We also thank Svendborg International Maritime Academy for access to their simulator facilities. The usability evaluation of the Maritime Communicator was planed and conducted in collaboration with Mikael B. Skov. Finally, we would like to thank the anonymous reviewers who's comments and questions have contributed to improving the manuscript.

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