Published in Qvortrup L. and Andersen P. B. (eds.) (2003) *Virtual Applications: Applications With Virtual Inhabited 3D Worlds.* Berlin, Springer-Verlag

Lessons From Being There:
Interface Design for Mobile Augmented Reality

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Introduction

Virtual 3D worlds used to be accessible primarily through display systems separating the users from the physical world and immersing them into a parallel computer-generated virtual reality. Today, virtual 3D worlds are being merged into physical space creating not only *virtual* but *augmented* realities (AR). Contrary to virtual reality, augmented reality facilitates mobility in the real world as well as a close relation between physical space and virtual objects. This makes AR an interesting approach for human-computer interfaces in mobile use-contexts.

Based on the lessons learned from developing “Being There” – an experimental prototype for distributed cooperative work – this chapter addresses the design of augmented reality interfaces for mobile computing devices. Augmented reality is discussed in relation to the concept of *context awareness* in mobile computing and is presented as an interface approach, in which designers must take into consideration the role of physical space on a very high level of contextual detail. One central question is guiding the discussion: how can the properties and use of physical space be analysed and described in a form supporting the creative design of new and fundamentally different human-computer interfaces such as augmented reality? Addressing this question, it is shown how the role of physical space in cooperative work can be formulated in Alexandrian design patterns specifying requirements for human-computer interfaces in a form that identifies desired qualities of an interface, without dictating specific design. From the implemented prototype, it is exemplified how design patterns as interface requirement specifications can be converted into creative interface design for augmented reality.

1. Interface design for mobile devices

The use of mobile computing devices imposes several challenges on the design of human-computer interfaces.

Providing highly relevant input to designers and developers within the mobile device industry here and now, much research on interface design for mobile devices is focused towards exploiting the potentials of existing technology better. This means coming up with new solutions, which overcomes the obvious limitations of present mobile technology: small displays, low network bandwidth and limited means of interaction. A number of approaches to these challenges are being explored such as the use of spoken interaction for reducing visual attention and tactile contact with the physical devices, and guidelines for graphical interface design being reconsidered in the context of small screens on mobile devices (see e.g. Bergman 2001). Especially the latter sometimes results in new design more or less contradicting the recognized trends within interfaces for desktop computers: Quality and resolution of images and graphical information representations for use in mobile device interfaces are being *reduced* to the limit of loosing their semantic value and information is being squeezed into displays by *removing redundancy* and sometimes cutting it up it into a *more complex* structure or hierarchy of sub-sections. Existing information content (on e.g. web pages) is being *filtered* and cut into smaller pieces in order to fit in on the displays of handheld PCs or WAP phones and reduce data transfer. These solutions all contribute to making data and communication accessible while being mobile.

Mobile computer use is, however, more than just a question of communication and information access while being separated from one's desktop, and the usability of mobile devices is not only influenced by technical limitations such as small screens, but also by the relation between their design and their use context. As opposed to desktop computing, users of mobile devices are typically characterized by moving through physical space and interacting with a series of objects and subjects autonomously moving in and out of the user's proximity. This results in use contexts, in which demands for information and functionality changes in accordance to contextual factors such as time, place and social constellations.

The implications of the use context are increasingly being taken into account within mobile HCI. Devices are being equipped with sensors for making them react on how they are being held, touched and moved (see e.g. Hinckley et al. 2000). Spatial, temporal and social *context awareness* is being explored as means of input for customising interfaces to specific situations or locations in time and space (see e.g. Benford et al. 2001) and displays build into eyeglasses are providing mobile users with computerized graphical overlays on the real world, typically referred to as *mobile augmented reality* (see e.g. Feiner et al. 1999). While the properties and use of physical space are often downgraded or left out in interface design for existing mobile technology in favour of more technical issues, the design of context aware and augmented reality interfaces are demanding explicit focus on such contextual factors, as these interfaces are inherently related to the physical space, in which they are used.

1.1. Context awareness and augmented reality

Whereas small displays and restricted means of interaction are obvious *limitations* of mobile technology challenging designers to come up with new solutions, the dynamic use contexts of mobile computing does not necessarily constitute a problem, which needs to be solved through design. On the contrary, continuously changing contexts can be viewed as a rich *potential* for interface design.

Making computer systems sensitive to or aware of changes in their use context, interfaces can be designed for adaptation to specific contexts or *habitats* (see Andersen and Nowack, this volume) defined spatially by location in space, temporally by location in time and socially by the presence of other people. Designing interfaces for adaptation to different habitats will not only facilitate reduction or simplification of the information and functionality available in specific situations when moving between habitats, but in doing so also minimize the need for explicitly focusing on and interacting with the device. Viewing context changes as means of input to mobile devices, physical space becomes a part of the human-computer interface, providing the user with information and functionality "just-in-place" (Kjeldskov 2002).

Mobile information services adapted to habitats do not have to run exclusively on mobile phones or pocket-sized PC's but can appear in various forms. In some museums for example, visitors are equipped with infrared headphones providing contextually adapted spoken information related to

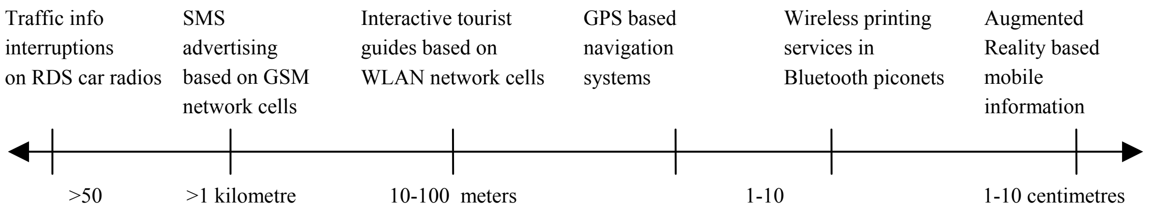


Fig. 1. Level of contextual detail in context aware information services for physically defined habitats

the works on display in specific rooms. On RDS enabled car radios, broadcasts are interrupted with spoken traffic messages or supplemented with text-based info on the radio's graphical display related to a delimited geographical area. Another example is the ability to charge mobile phone users different rates e.g. at home or at work according to their presence within specific GSM network cells.

Using mobile augmented reality, habitats (whether spatially, temporally or socially defined) can be represented even more sophisticated through visual augmentation of the user's physical surroundings. Specific locations, objects or persons can be complemented with visual information such as written text, icons, computer graphics, pictures and video, facilitating the reception of and interaction with virtual objects, information and actors, resembling that of their physical counterparts and thus demanding only a limited additional cognitive load. This has great potentials in situations where moving ones visual focus away from the physical world should be avoided (such as when driving or walking down the street) or in situations where interaction with computers is naturally related to interaction in physical space (such as in synchronous cooperative work). Other application areas include situations in which central information related to interaction in the physical world may be visually hidden or obscured (such as when e.g. manoeuvring a ship through thick fog).

Taking into consideration the role of physical space in computer use, context awareness and augmented reality challenges our usual notions of usability and involves the fundamental traditions of graphical interface design being reconsidered and new paradigms for interaction and interface design being explored.

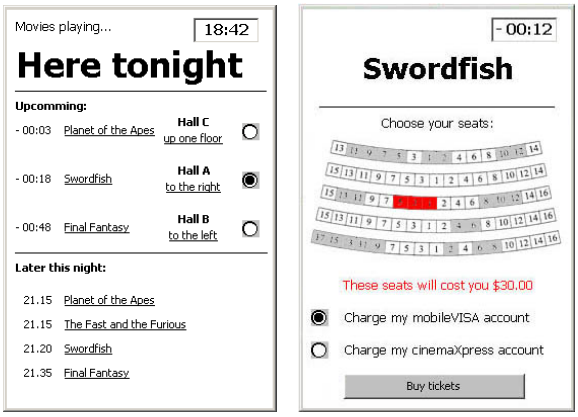
1.2. Level of contextual detail

From the examples above, it is clear that while context aware mobile information services do not have to have augmented reality interfaces, augmented reality interfaces on the contrary depends seriously on a close relation to their physical context. This consequently means that mobile augmented reality cannot be viewed as an *alternative* to context awareness, but is insolubly a sub-ordinated specific variation of this.

Differentiating context aware information services with reference to their relation to physical space, context-aware information services and tools can be plotted onto a continuum of *contextual detail* within spatially defined habitats, describing how detailed the interface reflects changes in the user's physical location. In one end of this continuum, augmented reality represents a high level of contextual detail while e.g. GPS driven navigation systems represent a lower level of contextual detail. In the other end of the continuum, e.g. SMS-based advertising broadcasted when entering specific GSM network cells and broadcasted traffic info interruptions on RDS radios represents low level of contextual detail.

Additional dimensions could be added to this continuum reflecting e.g. the level of *temporal* and *social* contextual detail, refining the picture of relations between existing context-aware information services further.

How accurate physical space and computer interfaces should be related in a specific habitat depends on which role physical space plays in that habitat. If a context aware information service or tool is to provide general information and functionality adapted to a specific room or building, it may be accurate enough to know in which room of a building or which building of a city a user is located, and provide an interface adapted for that room or building.



Movies playing... 18:42

Here tonight

Upcomming:

- 00:03 Planet of the Apes **Hall C** up one floor ○
- 00:18 Swordfish **Hall A** to the right ●
- 00:48 Final Fantasy **Hall B** to the left ○

Later this night:

21.15 Planet of the Apes
21.15 The Fast and the Furious
21.20 Swordfish
21.35 Final Fantasy

- 00:12

Swordfish

Choose your seats:

These seats will cost you $30.00

● Charge my mobileVISA account
○ Charge my cinemaXpress account

Fig. 2. Context aware interfaces for cinema information service available when entering the lobby (left) and waiting outside the hall (right).

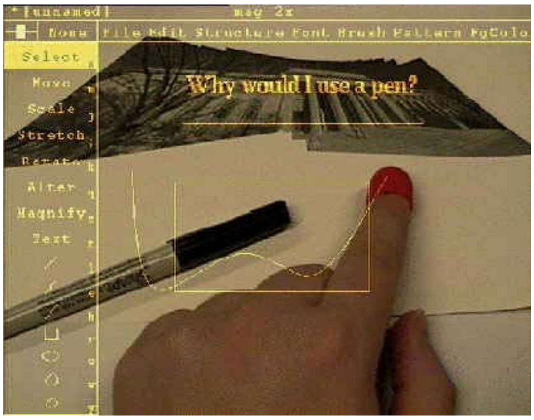


Fig. 3. Augmented reality interface for drawing tool enhancing the user's physical desk through computerised graphical overlay (MIT 1999).

Designing e.g. a context aware mobile device interface for a cinema facilitating movie information and ticket acquisition, this level of contextual detail could be achieved by making movie information and ticket acquisition available on small-screen devices in the physical space of the lobby and specific halls of the cinema (see figure 2) using e.g. wireless network cells or infrared beaming. Creating a meaningful relation between the interface and physical space on this level of accuracy would not demand an augmented reality interface. However, if a service or tool is to provide highly detailed computer-based information and functionality adapted to specific and delimited areas and objects in a room or building, a higher level of contextual detail is needed concerning the user's whereabouts in physical space and the placement of the interface within this space. Designing e.g. a context aware drawing tool, this level of accuracy could be achieved by spatially tracking the user, superimposing the computer interface onto physical desktop and facilitating interaction through the use of spatially organized physical tools and objects such as paper, pens, scissors etc. (see figure 3).

Compared to context aware mobile information services for low-level contextual detail, creating a meaningful relation between computer interface and physical space on the higher level of contextual detail exercised in augmented reality, increases the demands for knowledge about the user's contextual surroundings on two levels.

On a *technical* level, the user's location and orientation in space, proximity to objects and subjects surrounding him etc. has to be registered by the computer system with a very high level of precision. While several technologies for motion tracking are already available for virtual reality, appropriate technologies has yet to be developed for mobile augmented reality involving additional demands for facilities such as wireless operation, mobility and range.

On a *cultural and social* level, the properties and use of physical space has to be identified, analysed and described in order to capture qualities and limitations, which should be exploited or supported in the specific interface being designed. In relation to this analysis, it is important to notice that physical space does not have to be replicated in every detail in order to make a useful augmented reality interface. On the contrary, many significant properties of physical space such as e.g. gravity and distance are neither necessary nor appropriate in the majority of augmented reality interfaces in order to make them useful.

Apart from the analysis of the relation between physical space and mobile computing, converting this knowledge into specific interface design constitutes a major issue for the designers of such systems.

2. Analysing the use of physical space for interface design

When designing context aware or augmented reality interfaces, designers are faced with two general problems of HCI research.

Firstly, whereas guidelines for traditional WIMP (windows, icons, menus, pointers) based interfaces are widespread (see e.g. Preece et al. 1994, Dix et al. 1998 and Shneiderman 1998), the literature on human-computer interaction does not provide much input on how to design interfaces closely merged with their physical surroundings. Neither is much experience with the usability of such interfaces reported. General guidelines for graphical user interfaces, concerning concepts such as e.g. mental models, mapping, feedback etc. are of course also valid and valuable in relation to context awareness and augmented reality. However, most concepts and notions of HCI research only superficially address the role of physical space and the relation between interfaces and their physical surroundings. Secondly, HCI research may be criticized for primarily supporting *retrospective* measures and explanations of the quality (or lack of quality) in *existing* systems, and not providing a fruitful foundation for the development of *new* good interfaces (Nardi 1996).

Designing human-computer interfaces that differs fundamentally from the WIMP paradigm such as context awareness and augmented reality thus challenges both the scope and applicability of existing HCI research and calls for new approaches to design being explored. In order to support innovative design, such approaches must provide:

> *"(...) (1) a broad background of comparative understandings over many domains, (2) high-level analyses useful for evaluating the impact of major design decisions, and (3) information that suggests actual design rather than simply general design guidelines or metrics for evaluation. To be able to provide such expertise, we must develop an appropriate analytical abstraction that "discards irrelevant details while isolating and emphasizing those properties of artefacts and situations that are most significant for design"."*
>
> (Nardi 1996:69-70)

One of the problems with this perspective on HCI is the potential conflict between converting theoretical and analytical insight into suggestions for actual design without ending up in the pitfalls of either *dictating* specific solutions, thus limiting creativity and innovation, or leaving it all on creativity, with the risk of loosing control of the process and focus. To balance these, an analytical abstraction will be appropriate only if it captures the essence of the design problem in a form both *general* enough for innovation and at the same time *concrete* and *structured* enough for directing the creative efforts.

Designing for context awareness or augmented reality, such analytical abstraction must specifically be able to capture and differentiate the essential properties and uses of physical space in mobile computing in a way that inspires interface design merging the two, without simply just *replicating* the characteristics of physical space.

Inspiration to such analytical abstraction on design can be found in the works of architect and design philosopher Christopher Alexander. In his early work *Notes on the Synthesis of Form* (1964), Alexander presents a perspective on design of general value not limited to architecture and design of physical artefacts but also applicable within other areas such as computer interface and system design. In his principal work *A Pattern Language* (1977), this perspective is elaborated further into a method for describing and categorising design on a level of abstraction that captures the essence of existing form-context relations relevant for new design, while also supporting systematic structuring, interpretation and creativity.

2.1. Form and context

According to Christopher Alexander, good design is a matter of creating the right *fit* between form and context – form being the solution, the part of the world we can control and manipulate, context being the part of the world defining the problem and making demands on form. Design is thus not a question of form (or context) alone but a question of addressing the creation of *ensembles* fitting the two together. Ensembles of form and context exist on multiple levels. In a game of chess, some moves (form) fit the stage of the game (the context) better than in other stages of the game. In city planning, improving the city constitutes an ensemble of e.g. the form of expansion fitted to the context of the way the city works, the physical limitations and potentials and the necessity for such expansion (Alexander 1964:16). From this perspective, it is clear that the world cannot be definitively divided into categories of form or context as both form and context in itself can be considered ensembles of form and context. What is form in relation to a given context may be viewed as context of other forms and visa versa. Subsequently, fit (or misfit) can be obtained either by modifying the form to the context or by modifying the context (including existing forms) to the form. The latter, however, with the danger of breaking down existing fit in other ensembles. According to Alexander, design is typically situated in between these two extremes involving a mutual adaptation of form and context. Because form in itself also influence their own as well as other contexts, fit will consequently always be a dynamic rather than a static property of form-context ensembles, making design a potential infinite task.

The dynamic relation between form and context necessitates designers to introduce a borderline between form and context in a given design case or ensemble and specify what defines the problem and what constitutes the domain for possible solutions. Such borderline will, of course, always be superficial in the sense that it could have been drawn elsewhere. But another borderline also implies another relation between form and context and thus demands another form. In relation to this, Alexander (1964:17) emphasizes the tendency among designers to stretch the form-context boundary and wanting to redesign large proportions of the context rather than simply focusing on the objects, which they are supposed to improve. While this on one hand may be extremely impractical, it is on the other hand stressed as a fruitful way for designers to keep their eyes open to alternative solutions, others than the immediately obvious.

Pushed to the extremes, the development of new form perfectly fitted to its context demands either a complete description of the context or that a number of forms are tried out until a good one is found. Neither approach is realistic in itself. If the context could be described completely there would be no issue of design, only a question of construction. Randomised non-reflected experiments with different forms, on the other hand, cannot be characterised as a process of *design.* According to Alexander, understanding context and experimenting with form are instead inseparable elements in design as insight into the context influences the creation of form as well as experimenting with form influence the understanding of its context.

In relation to augmented reality user-interfaces for mobile devices, an Alexandrian perspective on design helps understanding the ensemble of devices and use better. First of all it is clear that shifting the use context of computing towards being mobile, requires corresponding form changes in order to maintain fit. Design that may have fitted very well into the context of desktop computing may be less appropriate in the context of being mobile. Supporting text input on mobile phones exemplifies this problem. Furthermore, the use of augmented reality displays implies a displacement of the form-context border, as display and means of interaction usually belonging to the context of interface design now becomes a part of the form domain. Apart from displacing the borderline between form and context, designing augmented reality interfaces for mobile devices also extend the scope of the context domain to involve the use of physical space and other objects and persons in the user’s physical surroundings, not necessarily relevant for design previously.

Extending the context may involve additional demands on the form but at the same time also widen the horizon of possible solutions.

Through the process of design, it is of course important to be able to evaluate and elaborate on form. According to Alexander, when people are exposed to misfit between form and context in poorly designed artefacts, they are typically capable of both identifying these and express how they are perceived defective. Fit, on the other hand, is neither easy to identify nor to describe because forms fitting their context appear transparent. This has the abrupt consequence that fit cannot be described independent of misfit but must be defined as *a form without misfit,* making it problematic to characterise the desired positive properties of a new form without having to refer to the elimination of known misfit. Misfit this way becomes a driving force in design through motivation and focus, subsequently introducing a demand for knowledge about the fit/misfit of similar form-context relations (either through practical experience or theoretical insight) among designers.

When designing something fundamentally new such as e.g. augmented reality interfaces, however, examples of misfit can be hard to come up with due to lack of precedence. In this situation, experiments with form play a significant role, not only as a way of creating fit but also as a way of generating misfit, challenging the designer and providing forces pointing towards solutions and extending his insight into the context.

Concrete cases of fit and misfit combined with insight into the context, describing when and why which forms fail or perform well can be systematised as *patterns* of design (Alexander et al. 1977), having the potential of directing designers towards creation of new solutions, recreating qualities of existing forms without replicating the form as a whole.

2.2. Design patterns

The concept of design patterns deal with some of the challenges of creative design disused earlier in relation to interface design: how to capture the essence of existing form-context relations (fit and misfit) while supporting creativity and facilitating a systematic approach to the problem domain.

Following Christopher Alexander's (1977) design methodology, a problem domain can be divided into a hierarchy of interrelated "patterns", collectively constituting a "pattern language" for designers across competences and demarcations. Every pattern within this hierarchy potentially relates to the implementation of one or more general patterns and typically points towards a number of more specific, sub-ordinated patterns supporting its own implementation (if such patterns exist). Each pattern themselves represent an empirically based formalised description of central properties and dynamics in the relation between form and context of a specific ensemble. Patterns identify and accentuate known examples of fit and misfit, and guide the designer towards the creation of new form through general examples useful for *inspiration* rather than *duplication.*
In his principal work, *A Pattern Language* (1977), Christopher Alexander provides such hierarchy of 253 interrelated patterns concerning architecture on three levels of abstraction: towns, buildings and constructions.

Though potentially related to a larger theoretical framework, design patterns are not in themselves abstract principles hard to apply in practical design. At the same time, patterns are neither so specific, that they loose value in development of *new* forms. On the contrary, design patterns are general concrete guidelines for the creation of fit, unifying insight into form and context pointing towards new form (as illustrated in figure 4) but without dictating specific design.

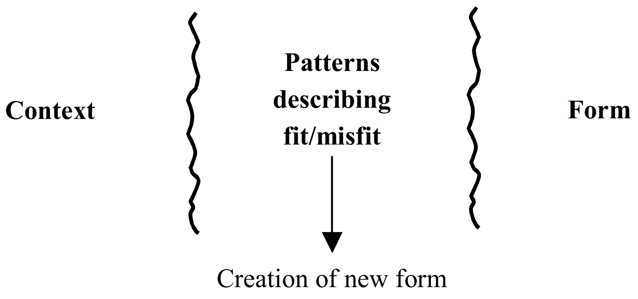


Fig. 4. Design patterns merging knowledge about context and form towards new design

Similar to grounded theory, design patterns emerge from empirical observations. But contrary to grounded theory, design patterns do not make up theory as such but are merely structured *descriptions* of form-context relations having been observed in the field. The process of identifying design patterns in a problem domain, however, very much resembles the process of generating theory from empirical data grounded in the real world. Identifying design patterns thus incorporates designers to observe a number of representative and reliable ensembles of form and context in a problem domain, and generate abstractions from this data, which captures the essence and explains the phenomenon on a level of general validity. Like generating theory from empirical data, identifying patterns of design is a long process, requiring designers/researchers to take a step backwards and elaborate on their understanding and ideas or even returning to the field for further observations and more focused studies. The methodology of Christopher Alexander (1977) does not provide much operational input on how to manage this process. However, the structure and interrelation of Alexandrian design patterns provide a valuable template aiding the formulation of patterns from ones empirical observations.

Alexandrian design patterns follow a uniform structure and graphical format, which makes them highly consistent (illustrated in figure 5). Each pattern is headed with a brief name and a photograph exemplifying its application. Following the photograph, the pattern is related to possible parent patterns, which it may contribute to the realisation of. This is followed by a concentrated problem statement, describing the essence of the problem addressed by the pattern in one or two short sentences (formatted in bold). Subsequently, the empirical background of the pattern and detailed insight into the context along with examples of fit and misfit are presented. This part is often accompanied by further pictures, drawings, diagrams etc. substantiating the empirical foundation. Finally, the solution to the problem (the essence of the pattern) is described in a few brief sentences (also formatted in bold) often supplemented with a general graphical representation. Each pattern is terminated with references to possible sub-ordinated patterns. A single design pattern typically takes up 3-5 pages.

The uniform format of Alexandrian design patterns has a number of advantages in the design process. First of all, the graphical layout and consistent use of photographs and text formatting makes collections of patterns (or pattern languages) easy to browse and be inspired by without having to read them all word by word. Secondly, the structured format facilitates design patterns being read on several levels of abstraction according to the need for input at a given time.

For browsing and overview, patterns can be read primarily through their names and photographs, pinpointing design issues and capturing possible applications of the pattern. For this use, the photographs heading each pattern play a significant role, often saying “more than a thousand words” and stimulating the user’s memory of a pattern. Selecting good photographs illustrating one’s design patterns is thus critical and should not be down prioritised (or left out).

For brief and summarised insight into the design issue addressed by a pattern, design patterns can be read exclusively through the short statements describing the problem and pointing out solutions. For this use, it is important that these sections are both brief and clear, and does not concern too deeply the background of the pattern.

Finally, for a full description, covering the empirical and theoretical foundations of a pattern, design patterns can, of course, be read in their full length. For this level of abstraction, it is important that the pattern provides insight, which substantiates both the problem statement and the suggested solution.

In practical use, designers will most likely shift back and forward between these levels of abstraction during the design process and e.g. 1) browse headings/photographs for a quick overview, 2) read into the problem and solution statements of those patterns, which seem immediately interesting, 3) read selected patterns in their full length for additional insight and finally 4) implement selected patterns using primarily their problem statements and suggested solutions, browsing between them using their headings and photographs.

2.3. Design patterns as user interface requirement specifications

Whereas the concept of design patterns has received much attention within software engineering and object oriented programming, less focus has been brought to this approach within human-computer interaction. Though several references to the work of Alexander exists within mainstream HCI literature (see e.g. Norman and Draper 1986, Norman 1988, Winograd 1996), only a few examples exists of HCI researchers actually applying the concept of design patterns and pattern languages in interface and interaction design. This even though that the concept of design patterns as originally indented within architecture has much more obvious relations to user interface design than to software engineering in respect to the focus on users and design meeting the demands and potentials of a use context. Among the most central work on design patterns for HCI are the work of Tidwell (1999) and Borchers (2001), illustrating the potentials of design patterns as user interface requirement specifications.

Through a comprehensive collection of interrelated patterns, Tidwell (1999) shows how the overall concept of a highly interrelated web of patterns can be applied to interactive software, describing highly specific issues of interaction design with a broad range of applications such as “going back to a safe place” and “disabling irrelevant things” while leaving out issues about implementation and user interface technologies. Exemplifying the strength of a pattern approach for capturing “timeless” examples of fit and misfit in interaction design, the majority of these patterns successfully balance the edge of being neither too specific nor too general for application outside the context within which they were identified.

Whereas Tidwell, however, does not strictly follow the format of Alexandrian patterns described earlier, making her patterns less inspiring to browse and rather superficial regarding their empirical background compared to the patterns of Alexander, Borchers (2001) carries the format of Alexandrian design patterns all the way through. In his patterns on the design of interactive exhibitions, dealing with more general interface issues than Tidwell such as “domain appropriate devices” and “immersive display”, Borchers shows how patterns for HCI can benefit from following both the structure and the level of abstraction characterising Alexander’s design patterns for architecture, facilitating a high level of interpretation.

While both the works of Tidwell and Borchers, however, focus primarily on the *identification* of patterns on interaction and interface design from existing HCI design, the actual *applicability* and *usefulness* of such patterns in the creation of *new* interface design still needs to be investigated and reported.

In the following sections, the practical applicability of design patterns for human-computer interaction is explored through a specific design case, dealing with the design of an experimental augmented reality prototype for distributed cooperative work. A number of empirically identified design patterns for computer supported cooperative work are presented, followed by a description exemplifying the actual application of these patterns in an augmented reality interface.

Compared to the HCI patterns of Tidwell and Borchers, the patterns described in this chapter are closer related to the use of physical space than to the experience with specific design solutions of existing well-performing human-computer interfaces. The reason for this is twofold. First of all, the use of physical space plays a significant role in the type of interface being designed. Secondly, the developed prototype explores interface design within an area with limited precedents. The design is thus not aiming at recreating specific qualities of existing tools as much as it aims at recreating the qualities related to the use of physical space and solving some general misfit in existing tools.

3. Design case: Augmenting a habitat for cooperative work

Workspaces for cooperation such as offices, meeting rooms, workshops etc. can be viewed as spatially, temporally and social defined habitats, facilitating specific cooperative activities at different times according to the people present or not present. Such workspaces often involves people in a workgroup moving around and artefacts being closely related to specific physical locations at specific times. Furthermore, physical space is frequently being reconfigured for a variety of use purposes: working individually or in groups, conducting presentations, holding meetings, organising and storing shared resources, socialising etc. When a workgroup is physically distributed, many of these properties and potentials of physical space are lost.

A variety of computer based tools for supporting cooperative work (CSCW) exists for supporting the creation of distributed shared workspaces facilitating sharing of files and applications as well as video-based interpersonal communication on ordinary desktop computers. While overcoming some of the problems of distributing a workgroup physically, these tools typically fail to support users being mobile in and take advantage of the properties of physical space, usually characterising cooperative work. Instead of providing the user with a transparent virtual space, within which cooperation can exist, CSCW tools thus typically constitutes new tools to be operated, in order to facilitate cooperation. This consequently results in an additional layer being introduced between the users and objects of a workgroup, creating demands for an intuitive representation of the system's conceptual model, restricting interaction and introducing a rather solid boundary between objects in physical and virtual space respectively.

Using mobile augmented reality interfaces to augment habitats for cooperative work through the creation of distributed virtual workspaces merged into physical space, introduces new potentials for the design of CSCW tools. Potentially relieving some of the problems of existing CSCW tools, mobile augmented reality interfaces for supporting distributed cooperation could enable a stronger relation between information systems and physical space as well as a higher level of mobility in the physical world while also present in a distributed virtual 3D space.

Exploring this hypothesis, an experimental augmented reality prototype for distributed cooperative work was designed and implemented. The interface design of this prototype was based on requirement specifications in the form of design patterns, describing the use of physical space in cooperative work in relation to examples of fit and misfit in existing CSCW tools.

3.1. Identifying design patterns for computer-supported cooperative work

During 1999, 12 design patterns was identified and used as interface requirement specifications for an augmented reality interface supporting a physically distributed workgroup. The basis of analysis leading to the identified design patterns was three-fold. 1) Literature studies on the role of physical space and artefacts in our daily lives generally (Hall 1966, Tuan 1977, Tillich 1933) and in cooperative work specifically (Kaptelinin 1996, Kuutti 1996, Obata and Sasaki 1998) provided a theoretical background for the empirical observations and analysis of collected data. 2) Empirical observations of cooperative work activities in physical space at the university of Aalborg (meetings, presentations, workshops etc.) with and without the use of computer-based tools provided specific insight into the use of physical space and artefacts. 3) Usability evaluations of a broad range of tools for computer-supported cooperative work (Microsoft NetMeeting, Teamwave Workplace, SGI InPerson, VirtualU, FirstClass, etc.) pointed out examples of fit and misfit in existing tools.

From the empirical observations, a number of distinctive characteristics and properties of cooperation in physical space were extracted and organised in a simple list of *issues*. Each issue was then discussed and reconsidered in relation to the others resulting in some being merged and others being left out. The remaining issues were then organized in a hierarchy and related to the theoretical perspective on physical space and labelled with a number of theoretical concepts. Similarly, the identified usability problems as well as examples of successful design in existing computer-based tools for supporting cooperation was listed, grouped and sub-ordinated each other. Where possible, usability issues were related to the corresponding use of physical space and labelled with theoretical concepts from the literature. Subsequently the two lists were merged into a hierarchy of preliminary outlines of 12 interrelated design patterns associated with the physical distribution of a workgroup, formulated in terms of physical space use with references to specific design. Finally the outlined design patterns were refined further, reformulated and supplied with an extended body discussing the problem addressed by the pattern and pointing out avenues for possible solutions. Photographs capturing the focus of each the pattern were then added.

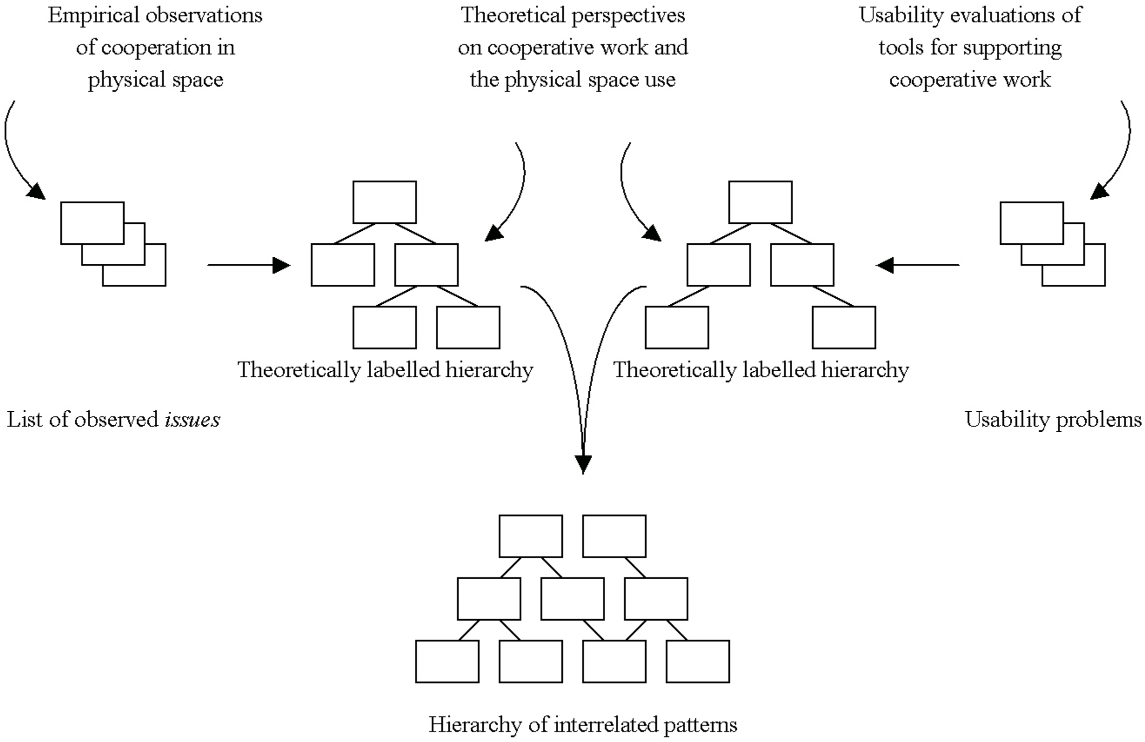


Fig. 5. The process of identifying patterns of cooperative work

4. Outlines of a pattern language for CSCW

From the original 12 design patterns identified, the following six had most significant impact on the interface design of the implemented prototype, and will be presented in this chapter in summarised form.

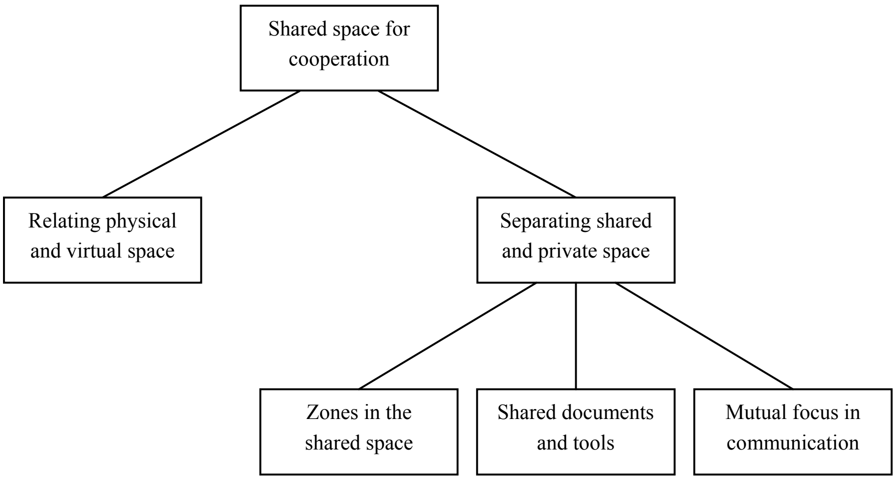
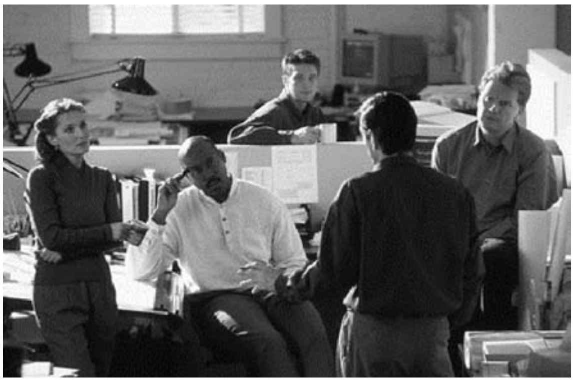


Fig. 6. Hierarchal structure of the identified design patterns for CSCW

Within the context of augmented reality-based interfaces for cooperative work these patterns can all be subordinated the realisation of Borchers' (2001) pattern H8 on Augmented Reality:

> "In situations where your system aims to recreate a real experience, use as much real instead of virtual environment as possible. Instead of trying to recreate all aspects of reality inside an artificial environment, augment the real environment with interactive technology that is not usually available otherwise"
>
> (Borchers 2001: 127-128)

1. Shared space for cooperation



When a group of people are working together, it is important to have access to a shared space for cooperation facilitating members of a workgroup relating to each other, sharing documents and engaging in communication, presentations, meetings, etc. When a workgroup is distributed physically, this space for cooperation is lost.

Observing cooperative work, it is obvious that the joint activity of a workgroup can be coordinated. Coordination typically takes place in three different ways: *scripted* through means such as plans, calendars and timetables, *communicatively* through written or spoken language or *instrumentally* through knowledge of each others actions. These ways of coordination requires that members of a workgroup have access to shared resources concerning their joint activities, can communicate and interact with each other and are aware about the actions and activities the workgroup as a whole. The closer a workgroup cooperates the more it depends on means for coordinating. Under normal circumstances, physical space plays a vital role as highly versatile medium for such mechanisms. When a workgroup is distributed physically, this medium is lost. Observing the use of tools for distributed cooperative work indicates that while scripted and asynchronous communicative coordination is typically supported very well through access to e.g. shared folders, e-mail based communication and discussion forums, it is hard to support instrumental and synchronous communicative coordination. While chat relays, video communication and application sharing have potentials in this direction, current implementations of these technologies are still rather limited.

Therefore:

Create a computer-based shared space for cooperation by connecting the individual workspaces of people in a distributed workgroup to each other. Within this space, facilitate information access and flexible communication and interaction among the group. If possible, support the maintenance of peripheral awareness about the presence and activities of others.

Create such shared space for cooperation by *relating physical and virtual space (2)* and *separating shared and private space (3)* with reference to *zones in the shared space (4), shared documents and tools (5)* and *mutual focus in interpersonal communication (6).*

2. Relating physical and virtual space

The use of computer-based tools or media in distributed cooperative work introduces a hard boundary between virtual objects and physical space, restraining the relation between the two. Each member of a workgroup consequently has to maintain an informational (virtual) space and a physical space, as well as an arbitrary relation between the two.

While physical space facilitates objects being spatially organised and related to each other in a meaningful way, according to their location in space, this facility is restricted when dealing with a mixture of physical and virtual objects.

Observing the use of tools for computer supported cooperative work indicates that physical and virtual spaces are highly separated, and that user's spend considerable efforts on maintaining a relation between the two, displacing the focus of activity away from the cooperation itself.

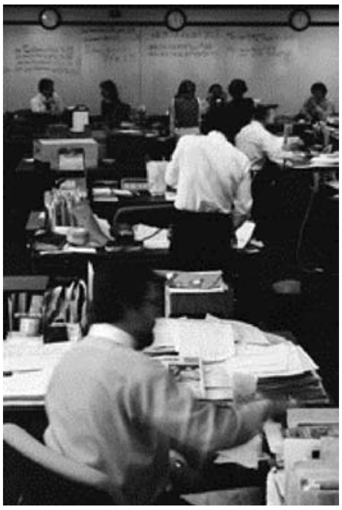
The lack of relation between physical and virtual space often results in a messy, confusing and unnatural organisation of the elements in the interface. In tools for supporting a distributed workgroup, shared objects, representations of other members of the workgroup, control panels, etc. are typically crowding the user's desktop in a very unstructured fashion without any relation to the physical space surrounding the tool. Such badly organised interfaces limits the usability of the shared space for cooperation, because fundamental operations such as changing focus from one object to another (whether virtual or physical), interacting with shared tools or communicating with remote users cannot be done without consciously focusing on interaction with *system.*

The problem can be described as lack of context awareness, making interaction in the physical world surrounding the system "invisible" to the system and visa versa. How accurate interaction in physical space should be reflected in virtual space depends on the specific context of use. Some applications such as augmented reality may require a very close relation while others may require only a superficial relation in order to support interaction.

Therefore:

Strengthen the relation between physical space and virtual objects by making the computer system context aware on a level of detail matching the specific need of the cooperative work activities being designed for. Design the means of interaction in a way that makes interaction in physical space a part of the human-computer interface.

3. Separating shared and private space



In a shared space for cooperation, it is important that members of a workgroup are not forced to be together at all times, but can separate from each other and retrieve to a space of their own. The separation of shared and private spaces is critical. Lack of separation breaks down the private space while too much separation isolates people from the workgroup.

According to Tillich (1933), the presence of private space constitutes a significant foundation for people's ability to act in shared space. Without private space, people have nowhere to retrieve to and feel secure but are constantly public, resulting in a feeling of root- and restlessness. Goffman (1959) addresses the same issue through the concepts of front- and backstage, while Tuan (1977) describes the problem as a matter of facilitating the creation of a *place* as opposed to *space:* a secure base, in which people are their own masters, in charge of the spatial layout and organisation of space and artefacts.

Observing the use of shared physical workspaces confirms the fine balance between shared and private space and furthermore indicates, that the separation is often dynamic, exemplified by e.g. people keeping the doors to their office open or closed towards the hallway at specific times.

In cooperative work, the importance of separating shared and private spaces is not only related to the individual need for a place of ones own. It is also simply a matter of facilitating individual work activities, relatively undisturbed by the presence and activities of others.

The separation of shared and private space is traditionally not an issue taking up much focus within CSCW, as the problem may remain invisible until private space is threatened by e.g. the creation of distributed shared spaces, exposing it to other people.

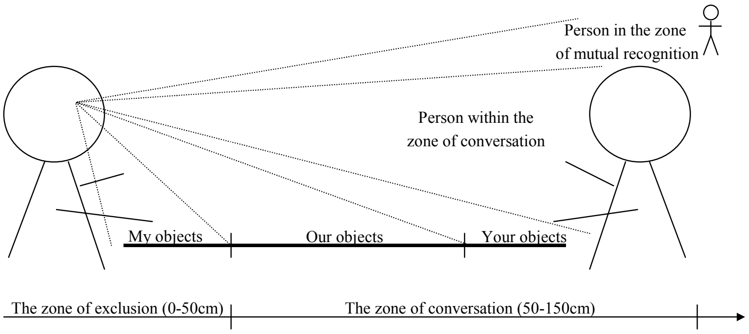
Therefore:

Provide each member of a workgroup with a private space facilitating individual work, clearly delimitated from the shared space. Make the private workspace half-open towards the shared workspace so that peripheral contact to the other members of workgroup can be maintained without people being able to keep a private workspace under surveillance.

4. Zones in the shared space

In cooperative work, it is important to be able to organize the shared space of a workgroup in a simple and comprehensible way, facilitating differentiation of objects belonging to the individual members and objects being shared by the group as well as easy exchange of private and shared objects among the members of the group.

In physical meetings around a central table, space is often divided into a number of zones, having a number of properties for organizing the shared space. Objects located within a person's intimate distance (15-45 cm) (Hall 1966) are considered belonging to this person while objects located within a person's personal distance (45-120 cm) but not within other people's intimate distance are considered shared by the people surrounding these objects. Objects within the social distance of a person (1,2 – 3,65 m) are also considered shared by the group while objects or persons within a person's official distance (3,65 m –) may belong to other groups. The division of shared space into zones supports an implicit reduction of complexity, clearly distinguishing between private and public objects as well as persons within close or remote proximity. The figure below illustrates such division of space in a physical meeting into specifically named zones (Obata and Sasaki 1998).



Therefore:

Divide the shared workspace into a number of zones corresponding to the zones of physical meetings facilitating intuitive identification of my objects, our objects, your objects as well as close and remote persons. Make the objects belonging each member of a group visible to other members within close proximity and facilitate easy exchange of objects between persons within close range.

5. Shared documents and tools

Cooperative work typically involves the use and organisation of a large amount of shared documents, diagrams, archives, drawings, etc. and the joint interaction with tools for modifying these. When a workgroup is physically distributed, the access to shared documents is limited and the cooperative use of tools is made difficult.

Cooperating in a shared physical space, shared documents etc. constitute a common frame of reference and a central means of asynchronous communication within the workgroup both through their informational content and their spatial relations, grouping, location, etc.
When a workgroup is distributed physically, the members of such group usually end up with multiple outdated versions of shared documents, and the common spatial relation between shared documents is lost, breaking the common frame of reference. In tools for supporting a distributed workgroup, it is thus important to support not only access to shared documents but also facilitate the members of a group jointly organising these documents in an appropriate way.

In relation to shared documents, tools for modifying these documents, whether individually or in groups, also plays a significant role in cooperative work as “mediating artefacts” (Kuutti 1996), supporting the transformation of the objects of cooperation and the instrumental coordination of activity. Observing the joint use of shared tools in physical as well as virtual space reveals a significant problem related to the regulation of turn taking: who is in control of the shared tool at a given time and how is the control taken by or passed on to another? In physical space, turn taking is usually regulated by cultural rules and cues, facilitating quick and easy handover. In tools for supporting distributed cooperative work, turn taking on the opposite, often involves a structured procedure to be carried out, facilitating control but limiting flexible use.

Therefore:

Within the shared workspace, make it possible to store, organise and retrieve shared information, and support the use of appropriate tools for modifying these individually or in groups. Make it possible to organise shared documents in a flexible way similar to the way one would organise physical documents: spatially, in stacks etc. If a shared tool can only be operated by one at a time, facilitate an easy regulation of turn taking.

6. Mutual focus in interpersonal communication

In physically distributed meetings, it can be difficult to maintain the mutual focus in interpersonal communication, which is implicitly established in physical space by virtue of visual orientation and body gestures.

Observing communication and interaction in physical meetings, the importance of visual orientation and body gestures of others becomes very clear. Establishing an implicit mutual focus and facilitating instrumental coordination of joint interaction among the members of a group, these means support the basic control of communication and joint interaction such as e.g. turn taking (passing the word on to another speaker) and indexicality (looking or pointing at someone or something while talking or interacting).

When people are physically distributed, the mutual focus characterising interpersonal communication in physical space is impeded, making it difficult to maintain a common frame of reference among members of a workgroup. This not only restricts interpersonal communication through a distributed shared space due to lack of properties such as mutual gaze-direction, but also lower the usability of shared tools and documents in synchronous cooperation.

Reducing the means of instrumental coordination, people consequently have to compensate for the lack of mutual focus and body gestures through other modes of operation such as meta-communication like “I now do this while looking at that…” or “do you see where I am pointing now…?” etc. This need for meta-communication further strains the channel of verbal communication and moves the focus of activity away from the objects of cooperation towards conscious operation of the tool itself.

Therefore:

Design the shared space for cooperation so that the gaze-direction and gestures of the distributed users such as pointing is reflects and represented in a natural and meaningful way. If possible, introduce into this representation some kind of reciprocity of gaze-direction, resembling the feeling of face-to-face contact in physical space.

5. Applying patterns to augmented reality interface design

In the following section, it is described how the six patterns of design presented above were applied to actual interface and interaction design. "Being There" is an experimental prototype, exploring the use of mobile augmented reality interfaces in relating a spatial habitat to a virtual information space on a high level of contextual detail. The prototype exemplifies how the visual augmentation of a private office for distributed cooperative work could be designed for access through a mobile device interface, exploiting the potentials and use of physical space in cooperative work. The illustrations show the user's perspective on the interface in an office already rich on physical objects and artefacts.

5.1. Creating a shared space for cooperation

The pattern on *creating a shared space for cooperation (1)* motivates the overall creation of tools for supporting distributed cooperative work. In the implemented prototype, such shared space for cooperation was created by augmenting the physical offices of each member in a workgroup with a computerised graphical overlay of a virtual 3D world, running on a central server and shared over high-speed network. This design first of all facilitated a much larger graphical interface than on traditional desktop monitors, leaving room for much more information without cluttering the interface. Wearing lightweight, semitransparent head mounted displays users at the same time remained mobile in the physical space of their offices while simultaneously also being present in the virtual shared space of the workgroup

The specific design of this shared space was realized through *relating physical and virtual space (2)* and *separating shared and private space (3)*.

5.2. Relating physical and virtual space

Supporting the relation between virtual objects and physical space, the implemented prototype was made context aware on a high level of spatially contextual detail, generating an impression of computer-based documents and tools being present alongside with their physical counterparts. This is illustrated in figure 7, showing the user's view of his physical desk, being populated with both physical and virtual objects.

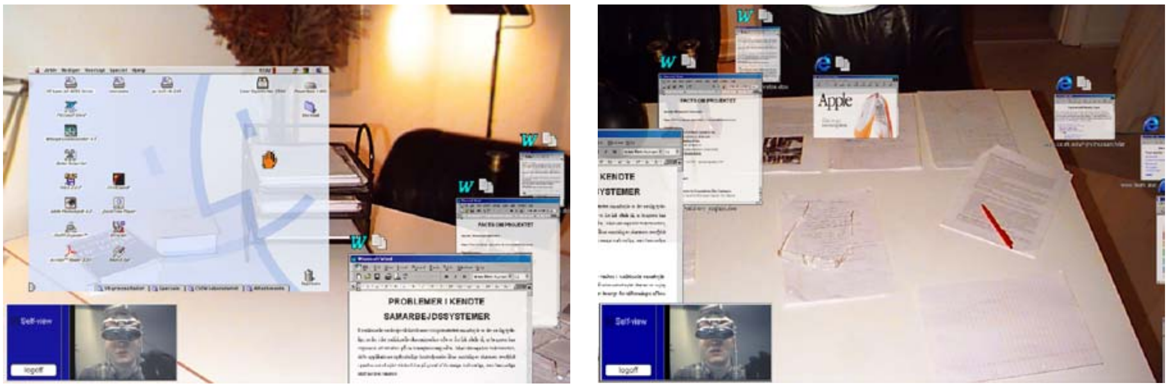


Fig. 7. Physical desk populated with physical as well as virtual objects

By turning his head, the user can change the view of the virtual world in the same way he would orientate in the physical world, preserving a consistent spatial relation between the two. In the lower left corner is a self-view, showing the video feed being transmitted to the other users of the system.

Blurring the boundary between physical and virtual space further, the interface design facilitates virtual objects being spatially organised in all three dimensions, being grouped, stacked, pushed further away or dragged into closer proximity. Additionally, virtual objects could have been directly related to physical objects, creating an even stronger relation between physical and virtual space. This was, however, not implemented.

Interaction is done by means of a dataglove facilitating virtual objects being grabbed, moved and modified with ones hand, in more or less the same way one would interact with physical objects. Rectifying some of the limitations of interaction in physical space, the user is, however, equipped with "stretchable" virtual arms, making him capable of reaching objects in virtual space within larger distance than in physical space.

5.3. Separating shared and private space

Implementing the pattern of *separating shared and private space (3),* the virtual space merged into the users physical office is divided horizontally into two overall areas. The area of the virtual space surrounding a user's physical desk is considered private and is not visible to the other users in the system, while the area facing away from the desk is shared among the group. This is illustrated in figure 8, showing a view of the private space on the left and the boundary between private and shared space on the right. Physically this boundary is marked with the end of the desk. In the computerised overlay this location, is marked/enhanced with a vertical line.

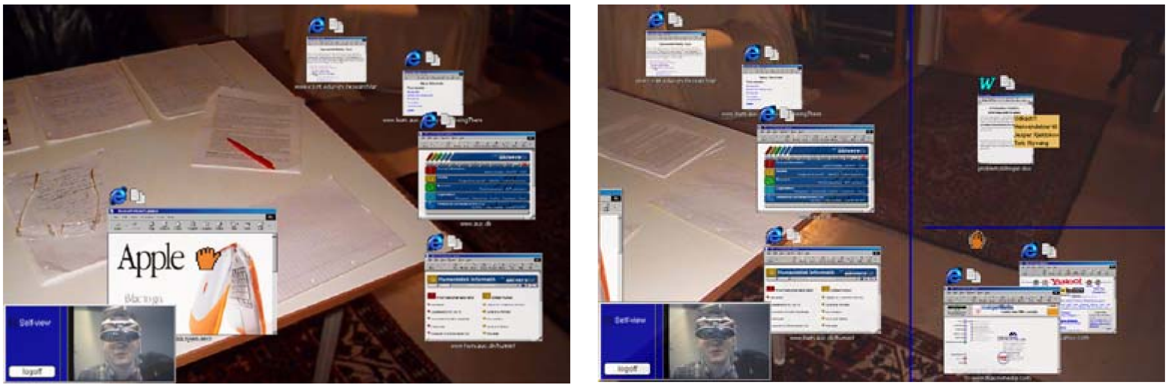


Fig. 8. The boundary between private (left) and shared space (far right)

The implemented layout of the interface to a large degree resembles the typical division of physical space in both private and shared offices, supporting peripheral contact to the workgroup while working in ones private space and facilitating an easy transition between private and shared spaces by simply turning around on ones chair. Exploiting this design further, documents can easily be exchanged (copied) among the group by simply dragging them from private to shared space and visa versa.

The specific design of the shared space is realised through *dividing the shared space into zones (4),* and supporting *shared tools and resources (3)* and *mutual focus in interpersonal communication (6).*

5.4. Dividing the shared space into zones

The layout of shared space (facing away from the physical desktop) is organised vertically in accordance to the pattern describing *zones in the shared space (4).* The implemented design more or less directly resembles the zones characterising a physical meeting.

Looking down his lap, the user has visual access to documents within the shared space, corresponding to the documents located right in front of him in a physical meeting (figure 8, left). This resembles the zone of exclusion, containing documents belonging to a specific person but visible to others in proximity. Looking upwards, the user has visual access to the shared documents of the workgroup, corresponding to the documents located in the zone of conversation between people in a physical meeting (figure 9). These documents can be organised and manipulated simultaneously by all users. Further upwards in the interface, the user sees the documents belonging to other members of the group: your documents (figure 9, right). The representations of the zone of exclusion of remote users are located immediately below their respective live video image (see section 5.6), supporting a natural mapping between the two.

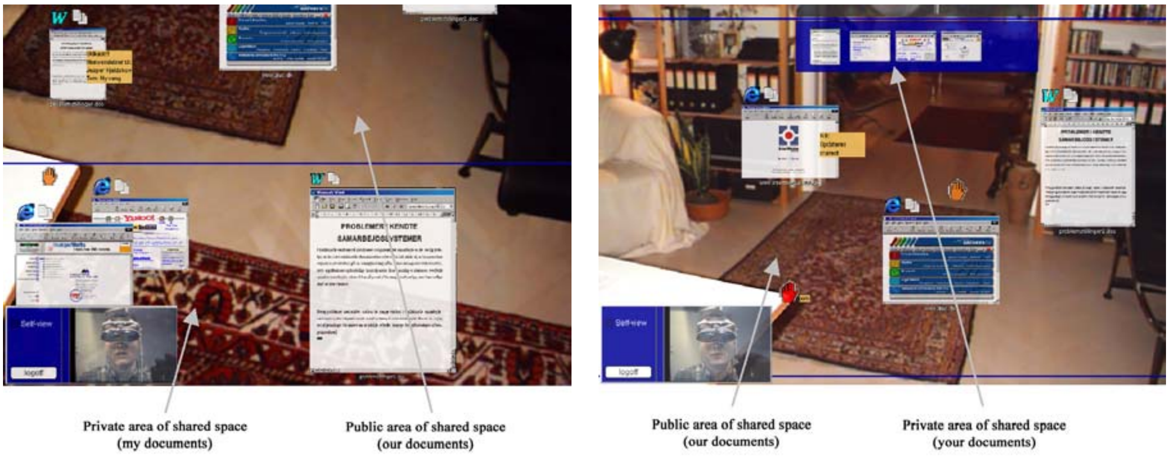


Fig. 9. The division of shared space into zones

Though designed in accordance with the zones of proximity in mind, the design of the shared space does not aim at resembling physical space in all aspects. Contrary to physical space, all users see the shared space from the same visual perspective, preventing users having to compensate for the mutual displacement characterising a "real" 3D world directly facilitating the use of spatial indexicality in communication such as referring to "the document down to the right".

5.5. Supporting shared documents and tools

In accordance to the pattern on *shared documents and tools (5),* the shared space for cooperation merged into the user's physical office supports the joint spatial organisation and interaction with computer based documents and tools.

Reducing the traditional boundary between documents and tools in computer artefacts, the interface design of the prototype facilitates documents (e.g. web pages or word documents) being editable in their corresponding tools by simply dragging them into closer proximity (figure 10).

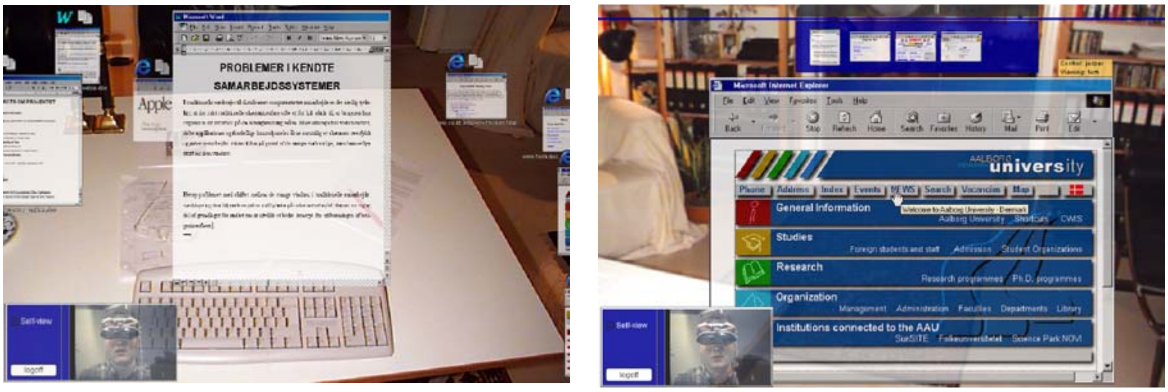


Fig. 10. Private and shared tools embedded into physical space

While tools in the private space (figure 10, left) are not visible to the group, tools in the shared space (figure 10, right) are by default shared among the users. As the multi user tools available in the prototype (word processors and web browsers) can only be operated by one user at a time, regulations of turn taking have been implemented. Resembling the turn taking in physical space, control over a shared tool is taken by another user simply by starting to interact with it. While this regulation of turn taking may result in anarchy and a constant battle for control, it on the other hand facilitates turn taking being controlled by cultural rules rather than through formalized procedures.

5.6. Supporting mutual focus and interpersonal communication

Looking straight into the shared space, the user has visual access to the other members of the workgroup facing the shared space through live video feeds (figure 11). In accordance to the pattern on *zones in the shared space (4),* the vertical location of these video images resembles the location of other people's faces in a physical meeting.

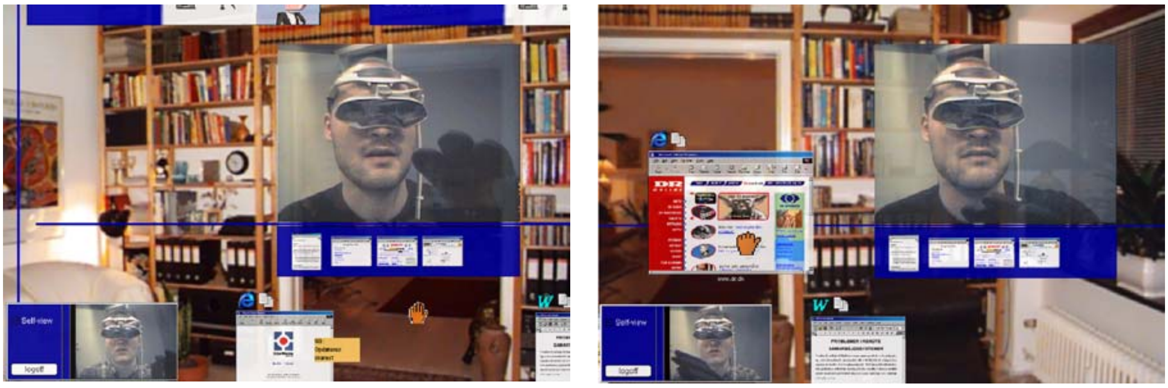


Fig. 11. Gaze-direction represented by the horizontal location of live video in shared space

Implementing the pattern on *mutual focus in interpersonal communication (6),* a remote user's gaze-direction in the shared space is reflected by the horizontal location of his video image in the shared space, thus causing video images of remote users to slide from left to right according to their orientation. This is illustrated in figure 11.

While very different from the way physical space works, this design has a number of advantages. First of all, it supports a simple cue for revealing the visual orientation of other users, making it possible to determine what remote users are looking at in the shared space. Secondly, an approximation of face-to-face contact is supported by the reciprocity of video image locations, meaning that if I look towards the video image of you, you will also be faced with the video image of me, providing valuable assistance in the establishment of interpersonal communication. This reciprocity is not available in traditional video based communication tools. Thirdly, if a user is not facing the shared space, no video image will be available, preserving the privacy of private space. In accordance with the pattern on *zones in the shared space (4),* remote users facing away from the shared space are represented as distant avatars in the zone of mutual recognition (in the top of the interface), supporting peripheral awareness (figure 12).

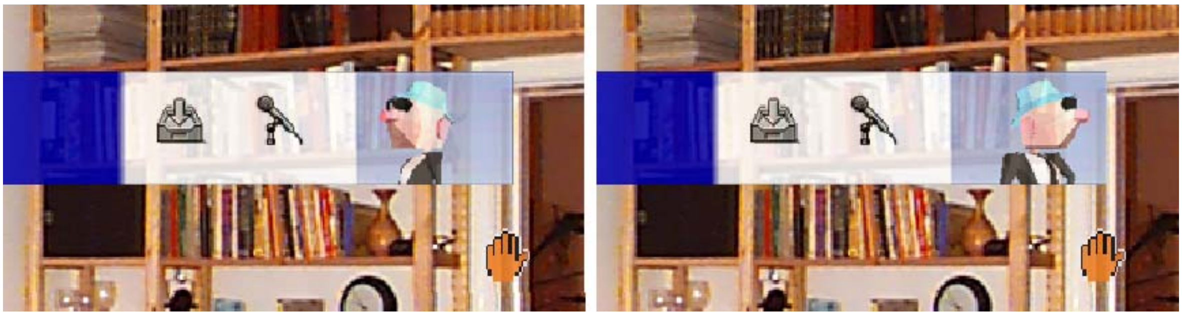


Fig. 12. The gaze-direction of remote users represented through the orientation of avatars

Providing each user with a distinguished pointer in shared space supports the representation of pointing in shared space but does not represent actual body gestures.

6. Lessons from Being There

The presented prototype exemplifies what a mobile augmented reality interface for distributed cooperative work *could* look like in order to support the properties and use of physical space, described earlier. The lessons learned from developing Being There can be divided into three sections:

1. Augmented reality interface design
2. Mobile augmented reality
3. Using patterns in interface design

6.1. Augmented reality interface design

Apart from being tested extensively by the developers, the design was evaluated through interactive exhibitions at Intermedia Aalborg in August/September 1999, during which a total of 25-30 people unfamiliar with such interfaces tried out the system in approximately 10 minutes each. During use, people were asked to “think aloud” communicating their comprehension and intentions when interacting with the system. Following use, people were informally interviewed about their experience with the system.

The evaluation showed that even though the graphical performance of the system was not optimal, the design demanded little instruction being carried out. Users typically had no problems understanding the relation between physical and virtual space and using the system for spatially organising virtual objects in physical space as well as orientating in virtual space by moving physically. They often walked right up and used the system. Some users, however, expressed a wish for linking virtual and physical objects, others expressed wishes for real 3D representation and stereoscopic projection, which was not facilitated in the prototype.
Users showed little or no problems differentiating between private and shared space and exchanging documents with each other. Some, however, expressed a wish for a clearer graphical identification of the boundary between the two, which can have been affected by the lack of natural demarcations of private and public areas in the physical space of the exhibition area. The division of shared space into zones was also easy to comprehend. Users expressed that they found the location of video images straight ahead of them natural and easy to use, and that the location of documents virtually in their lap supported a feeling of ownership.
While users easily engaged in interpersonal communication through the video links, the representation of gaze-direction was, however, reported difficult to understand and rather confusing by first-time users. Suggestions of other designs were made, e.g. indicating viewing direction through a small compass below each video image. Users communication through the system for a longer period of time, however, found the representation of gaze-direction very practical and easy to use, expressing that it actually supported their communication and interaction.
Though very intuitive at first, direct manipulation of virtual objects using the dataglove was reported demanding, as it required large physical arm movements for even simple operations. While maybe related to the relative low frame rate and high response time of the prototype, similar problems are also reported in the use of high-end virtual reality installations without these limitations (Kjeldskov, 2001), indicating that absolute input devices may simply be problematic for some types of interaction in virtual space. In both cases, using a relative pointing device would demand smaller physical movements.

The evaluation of Being There indicates that augmented reality interfaces exploiting the potentials and use of physical space and populating it with virtual objects have a high level of immediate usability, although fundamentally different from traditional human-computer interfaces. The virtual implementation of qualities found in physical space does, however, not demand physical space to be replicated in all aspects, but can be achieved through design inspired by it leaving designers room for creativity, exemplified by the unnatural representation of gaze-direction. On the contrary, implementing natural properties of physical space may result in limited usability as exemplified by the glove-based interaction technique.

6.2. Mobile augmented reality

Though not suitable for mobility outside a dedicated physical office due to the use of stationary electromagnetic tracking devices, the implemented prototype provides input on the design and usability of eye-glass based mobile augmented reality, relating physical space and user human-computer interfaces on a high level of contextual detail.

Addressing the challenges of mobile HCI described in the beginning of this chapter, Being There shows how separating the computing device from the graphical interface and embedding the display into the user's eyeglasses can increase the limited screen real estate of mobile computers. Covering a large percentage of the user's visual field of view at all times does, however, not necessarily mean that it should be completely filled with graphical information at all times. In most mobile use contexts e.g. when walking down the street, the primary advantage of the relatively large screen real estate of an augmented reality interface is not the amount of information potentially squeezed into the interface. It is rather the ability to capture the user's visual attention and locate small bits of information at the appropriate spatial location within his visual view, enabling the user to receive information without having to pull out and hold a physical device. As physical space is typically already abundantly populated with objects, artefacts and people (illustrated on figure 7–12), designers of mobile augmented reality interfaces must balance the weight of embedding virtual objects into physical space without creating an explosion of complexity.

Exploring the potentials of context awareness in mobile device interfaces, Being There shows how virtual information can be merged successfully into specific locations surrounding the user, preserving a dual focus on the computer interface and the physical world. While the prototype primarily exemplifies how a *spatially* defined habitat could be represented through a context aware mobile information service, mobile augmented reality could also facilitate the representation of temporally and socially defined habitats through similar design, taking these contextual factors into consideration.

In relation to the limited means of interaction characterizing mobile devices, the use of augmented reality in Being There does not indicate an evident path for solutions. On the contrary one could claim, that the problem of interacting with mobile device interfaces is in fact increased in the light of augmented reality by removing the usual relation between physical input device and visual output device. While walking down the street, how does one interact with virtual objects floating in space? Apart from the use of simple pointing devices, interesting areas of research counts the use of speech (Sawhney and Schmandt 2000), eye-movements (Duchowski and Vertegaal 2000) and even brainwaves (Hjelm and Browall 2000) as means of input, potentially applicable within the context of mobile augmented reality.

6.3. Using patterns in interface design

The employment of Alexandrian design patterns in the development of Being There exemplifies how the properties and use of physical space can be analysed and described in a form supporting creative interface design for augmented reality. In the specific design case, the methodology of Alexander constituted an appropriate analytical abstraction by describing interface requirement specifications through a series of design patterns, balancing the need for facilitating creativity in new design while approaching the design problem in a systematically and structured way. The identified patterns specifically played a threefold role as *design tool, communication tool* and *structure tool.*

As a *design tool,* the patterns reduced the complexity of the specific form-context ensemble in focus and pointed towards new solutions by identifying and describing key issues of the context and existing forms relevant for design while discarding irrelevant details. As no specific solutions were dictated, the patterns challenged the designers to be innovative within the frame of the patterns.

As a *communication tool,* the patterns supported the accumulation of the problem domain analysis and mediated this knowledge on to the process of design. During design, the patterns worked as a common frame of reference in communication within the design team, supporting a high degree of subjective interpretations within a common frame of understanding.

As a *structure tool,* the web of patterns divided the form-context ensemble into a series of interrelated tangible design problems to be addressed explicitly. Each isolated pattern furthermore supported the structure of the design process by dealing with a clearly delimited area of the form-context ensemble.

While design patterns are great for supporting communication and a structured approach to creativity, they are in themselves, however, too general for implementation without further efforts being made. At some point of the design process, patterns must thus inevitably be complemented with additional and more detailed requirement specifications, specifying exactly *how* the interface should look and work and *how* it should be constructed in order to do so. In this perspective, design patterns may be most valuable in the *early* phases of a software development process.

6.4. Limitations of this work

As the primary focus of this project was the preliminary studies of the design potentials and problems of mobile augmented reality, the prototype was never intended to make up a fully implemented system suitable for real-world use, but should rather serve as a *proof of concept.* Full-scale usability studies of the interface design in real distributed cooperative work setting were thus not conducted, naturally limiting our ability to assess whether or not the design really have the intended qualities of physical space and would perform well over a longer period of time.

7. Conclusions

In this chapter, I have presented mobile augmented reality as a possible human-computer interface approach for context aware information services with a very detailed relation between physical and virtual space. In the light of a number of limitations within HCI research in relation to the creation of *new* interface design, I have presented the concepts and methodology of Christopher Alexander, suggesting the relations between ensembles of form and context being described as patterns of design. Using this approach, I have shown how a mobile augmented reality interface for supporting distributed cooperative work can be designed from empirically identified design patterns, capturing the role of physical space in cooperative work.

The implemented prototype shows that physical and virtual space *can* be related in a mobile augmented reality interface and that locating virtual objects in the user's physical surroundings *can* be useful in a mobile device interface. The evaluation of the prototype indicates that such interfaces *can* be comprehended and utilized by ordinary users.

Acknowledgements

The author thanks Tom Nyvang who participated in the identification of the original 12 design patterns and the development of the prototype. Acknowledgements are also paid to Ellen Christiansen and Erik Granum for engagement and enthusiastic supervision on the project and their participation in constructive discussions.

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