Roomware for Cooperative Buildings: Integrated Design of Architectural Spaces and Information Spaces

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Abstract. In this paper, we introduce the concepts of "cooperative buildings" and "roomware" and place them in the context of the integrated design of real, physical, resp. architectural spaces and virtual, resp. digital information spaces. By "roomware" we mean computer-augmented things in rooms, like doors, walls, furniture, and others. The general approach is detailed via examples from the i-LAND project where we develop several "roomware" components in order to realize an interactive information and cooperation landscape, e.g. an innovative work environment for creativity teams. We describe the current realization of i-LAND which includes an interactive electronic wall, an interactive table, computer-augmented chairs, and a mechanism for assigning physical objects as representatives of information objects in the virtual world.

Keywords. cooperative buildings, shared workspaces, physical space, architecture, virtual world, information space, augmented reality, roomware, furniture, dynamic offices, team work, creativity support, CSCW, human-computer interaction.

1 Introduction

Introducing information and communication technology already changed work processes and the content of work significantly. However, the design of work environments, especially physical work spaces such as offices and buildings, remained almost unchanged. Neither new forms of organizations nor computer-supported work practices have been reflected in relevant and sufficient depth in the design of office space and building structures. In the future, work and cooperation in organizations will be characterized by a degree of dynamics, flexibility, and mobility that will go far beyond many of today's developments and examples. On demand and ad hoc formation of teams, virtual organizations, physically distributed and mobile workers are only initial examples of the work practices and organizational innovation to be expected. Contents and participants as well as contexts, tasks, processes and structures of collaboration will be changing frequently, in various ways and with an increasing rate of the innovation cycle. It is time to reflect these developments in the design of equally dynamic, flexible, and mobile work environments.

The paper is organized as follows. First, we introduce the concept of a "cooperative building" and describe three dimensions relevant for determining the scope of this concept. Second, we focus on the integrated design of the physical space and related information spaces. This includes the introduction of the "roomware" concept and the so-called A^3-environments based on the requirements derived from three sample scenarios. The main part of the paper is then devoted to the i-LAND project and the presentation of the roomware components we have developed. Finally, we put our work in perspective to related work and close with comments on future work.

2 Cooperative Buildings

We propose the concept of a *cooperative building* as a flexible and dynamic environment that provides cooperative workspaces supporting and augmenting human communication and collaboration. By the choice of this term we want to indicate that the building serves the purpose of cooperation and, at the same time, it is also "cooperative" towards its inhabitants and visitors. This is to say that the building does not only provide facilities but it can also (re)act "on its own" after having identified certain conditions. According to our vision, it will diagnose problems, provide information, establish connections between people, and offer "help". It will adapt to changing situations and provide context-sensitive information according to knowledge about past and current states or actions and, if available, about plans of the people.

While the term "building" implies strong associations with a physical structure, our concept of a cooperative building goes beyond this. It is our understanding that a cooperative building originates in the physical architectural space but it is complemented by components realized as objects and structures in virtual information spaces. Combining real and virtual worlds in a computer-augmented environment allows us to design enabling interfaces that build on the best affordances of everyday reality and virtuality. As designers of human-computer interaction or rather human-information interaction and human-human cooperation, we seek to use the best aspects of each. This perspective is inspired by related approaches in augmented reality (Wellner *et al*., 1993), ubiquitous computing (Weiser, 1991), tangible bits and ambient media (Ishii & Ullmer, 1997) described in the related work section. We will provide examples of our realizations, e.g., in the i-LAND project in subsequent sections.

A related aspect is that a cooperative building is not restricted to one physical location. Our perspective encompasses a distributed setting with remote locations where people work and dwell. The remote location might be an office building at another site of the organization or in a building at a client's site, a teleworker's small office at home or the temporary hotel room of a salesperson "on the road". Within the framework of a cooperative building, people can communicate, share information and work cooperatively independent of the physical location. In contrast to today's restricted desktop-based videoconferencing scenarios, we envision a seamless integration of information and communication technology in the respective local environment. This results in more transparency and a direct and intuitive way of interaction, communication and cooperation in distributed environments. This approach builds on our earlier work on ubiquitous collaboration (Streitz, 1996) and is in line with the work on media spaces (Bly *et al*., 1993) and ubiquitous media (Buxton, 1997).

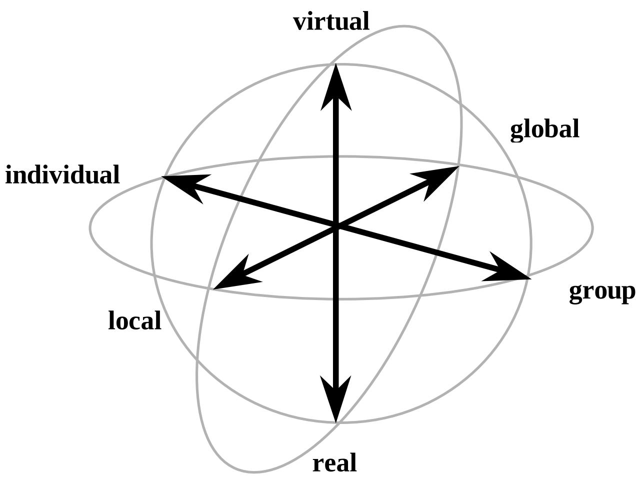

Fig. 1. Three dimensions of cooperative buildings.

For our thinking it was useful to distinguish the three dimensions shown in Fig.1. While each of these have been addressed before, the integrated global picture has still to be constructed. A central aspect is the *"real vs. virtual world" dimension* or, using a different terminology, the physical or architectural space vs. the digital information space or cyberspace. While each terminology has its own set of connotations, we will use them here more or less interchangeable. Our day-to-day living and working environment is highly determined by the physical, architectural space around us constituted by buildings with walls, floors, ceilings, furniture, etc. They constitute also rich information spaces due to the inherent affordances either as direct information sources (e.g., calendars, maps, charts hanging on the walls, books and memos lying on the desks), or by providing ambient peripheral information (e.g., sounds of people passing by). With the advent of information technology the situation changed dramatically. Information is a resource that is more and more available via the computer, usually the desktop computer. People tend to view information now as primarily available by "diving" into cyberspace. The situation changed not only in terms of having a different "place" or "location" for, in principle, the "same" information (e.g., on-line calendars, e-mail, electronic documents, on-line data bases) but - more important - in terms of new categories, constellations and ways of presenting information. Some of it has no counterpart anymore in the real physical world as, e.g., artificial worlds, virtual reality. Furthermore, in many cases it will be updated more often than other sources of information.

There is another aspect of the "virtual" part of this dimension. It refers to the situation where people are not in one physical location but in remote, distributed locations. Associated terms are virtual meetings, virtual teams, virtual organizations, but one has to note that the people, for example, of a virtual team, participating in a so-called virtual meeting are still real people[1] in real physical spaces. If one goes beyond standard desktop video conferencing, one is faced with challenging design issues for creating a "shared" background setting in which the distributed members are placed (Buxton, 1997).

This interpretation of "virtual" is, of course, closely related to the *"local vs. global context" dimension*. This dimension addresses the issue that we have to design the local environment with respect to the requirements resulting from its two roles. One role is to augment individual work and support group work in face-to-face meetings. The other is to provide an environment that facilitates the global cooperation of distributed people. While there is an intuitive understanding of the meaning of "local" vs. global", one has to look at it in more detail. The term "local" is often used synonymous with co-located or "same place". Think for example of a standard office or meeting room. But what is the scope of the "same place" ? Is the hallway part of it when the door is open ? Where are the boundaries " ? In contrast, where does a "remote" place begin ? Is the meeting room on the next floor local because it is "near by" or a remote place ? Does the notion of remote location and global context start in another building, another city or another continent ? In the i-LAND project, we will use sensors for determining positions. Thus, the information devices know where they are, what their local and global context is, and the cooperative building can be provided with information about the location of people in relationship to the devices.

In i-LAND, we currently concentrate on the design of "near by" local environments, i.e. within one building, but we keep in mind that they will also serve as local counterparts for global cooperation. Each venue of a global distributed cooperation scenario has to offer much more than the current individual desktop office. This implies that one has to look "beyond desktops" when designing this type of support.

A third relevant distinction is based on the *"individual vs. group" dimension*. It emphasizes that the type of support should be able to distinguish, for example, between different degrees of coupling shared workspaces. This is based on our earlier work on cooperative hypermedia systems (Streitz, 1996). It should be possible to determine the degree of coupling by the users and provide awareness about who is sharing what and to which degree. This dimension reflects also the implications of different phases of team work: plenary presentation and discussion in the complete group, splitting up in subgroups, working individually on an assigned task, resuming again for the integration of ideas and merging of intermediary results, etc. At a more general level, this dimension addresses the differences in social contexts of work arising from different organizational structures.

In summary, it is our opinion that the realization of a "cooperative building" has to pay attention to these three dimensions in order to constitute the basis for designing, using, and evaluating the Workspaces of the Future.

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[1] There is no space to address the concept of avatars here. They certainly have interesting implications for the issues discussed here.

3 Integrated Design of Architectural Space and Information Space

In our current work, we concentrate on two of the three dimensions discussed in the previous section: the real vs. virtual and the individual vs. group dimension.

In order to develop a cooperative building or parts of it, we follow a human-centered design approach. The human is at the center of our considerations. However, the human is part of a group or a team and the team has to be viewed in the context of an organization. Combining this with the previous goal of an integrated design of the physical space and the information space, we arrive at the following four spaces (figure 2) which need to be addressed in the overall design:

The *cognitive space* of the individual processing content in order to solve the tasks, the *social space* reflecting work practices and organizational context, the *physical space* including the architectural components of the building and the roomware, and the *information space* provided and mediated by networked information devices providing the functionality needed for working on the task.

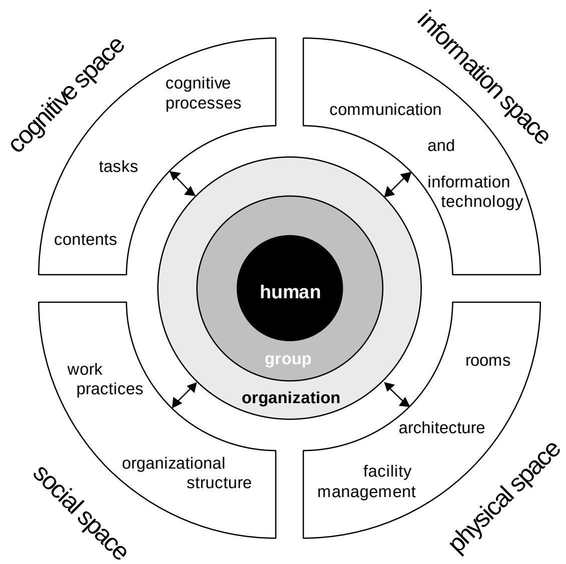

Fig. 2. Design spaces of cooperative buildings.

Our design of the cooperative workspaces provided by a cooperative building is driven by example application scenarios but we are not limited to them. In the following, we describe scenarios, derive requirements and present proposals for design.

It is our vision of the workspaces of the future that *the world around us is the interface to information* (re)presented via ubiquitous devices, some of them visible, others "invisible" in the sense that they are embedded in the physical environment. We anticipate a situation, where we do not have to go to a specific place (e.g., the desktop computer in an assigned office) to interact with information and where people interact with each other mediated by digital information. Instead, ubiquitous and interactive landscapes for interaction and cooperation augment our reality.

3.1 The *Roomware* Concept

Inspired by previous work on augmented reality and ubiquitous computing and our own work on electronic meeting rooms, we describe now two application scenarios which served as starting points for our roomware concept.

Scenario One: A meeting in the hallway. Meeting a colleague by chance in the hallway and starting a discussion might result in the intention to explain something by drawing a sketch on the wall and annotate it by scribbles. Besides the fact that this is usually not accepted in our office buildings, in current buildings with existing technology one could not store and later modify these elements of the discussion. It is also not possible to search for related information in a background information base and to link this information to the sketch and the scribbles on the wall. When the two are finished, the result of the work should disappear from the wall but still be accessible at any other place in and also outside the building. In the future, we like to be able to turn to the wall and do just this. Think of the wall as an interactive wall or as one being "covered" by a high resolution electronic wallpaper providing the functionality needed and being networked to other places.

Scenario Two: Dynamic team rooms. In typical team work, a team meets and often divides up the work by assigning subtasks, then breaks up so that individuals and subgroups can go off to do their work. After some time, perhaps the next day, the full team meets again and discusses the results which form the basis for the next phase of cooperation. In a time-critical situation, it would be very useful if one can reduce this cycle time of full team meeting/ subgroup meetings. An alternative is to provide ways for subgroups to split up *during the meeting* in the same room, do their work, rejoin and then immediately merge the results. Providing adequate information technology support for this scenario requires a team or project room which is equipped with components and resources which are very flexible so that they can be reconfigured dynamically and on-demand in order to meet the requirements of changing team work situations. Our analysis of this scenario includes a plenary situation and different subgroup or individual work constellations. The plenary is characterized by the full team sitting in chairs and facing a large public display. An example of subgroup work is that people move their chairs and group them in one corner of the room, discuss their task and exchange ideas. Another subgroup walks over to an ad-hoc meeting table, stands around it, views and edits tables and diagrams. A third constellation is that people walk up to a whiteboard at the wall, draw sketches and annotate them with scribbles. Of course, it might be the case that some of these "subgroups" consist only of one person using the devices for individual work. It is our vision that the chairs, the table, and the wall are interactive devices providing support for these cooperation and interaction situations via embedded information technology.

Our approach to meet the requirements of these scenarios is based on the roomware concept. By *roomware* we mean computer-augmented things resulting from the integration of room elements (e.g., walls, doors, furniture like tables, chairs, etc.) with computer-based information devices. The resulting roomware components are interactive. They provide support for the creation, editing, and presentation of information. They are networked and therefore have access to worldwide information. The chairs and the table are also mobile due to wireless networks and stand-alone power supply.

The general goal of developing roomware is to make progress towards the integration of architectural spaces and information spaces. In the context of CSCW, we have a specific goal, i.e. to develop reusable components which can be tailored and composed to form flexible and dynamic "cooperation landscapes" serving multiple purposes: team or project rooms, presentation suites, information foyers, etc. Both goals have in common that we also have to develop new forms of human-computer interaction for multi-user, multiple-displays environments. In section 4, we describe the initial set of roomware components we develop in the i-LAND project. It consists of an interactive electronic wall (*DynaWall),* an interactive table *(InteracTable),* and mobile and networked chairs with integrated slate computers *(CommChairs).*

3.2 A^3-Environments

In our discussion of the local vs. global dimension, we raised the issue of identifying and locating devices in buildings and in global distributed environments. Using sensors, one can acquire information on who (people, roomware components) is located where, connected with whom and interacting with whom. This can be used to structure the cooperation process among people and to provide the corresponding means and information needed by an individual or a team. The next scenario illustrates part of this idea.

Scenario Three: The room that knows you and your team. A project team enters the room. The "room senses" the members of the team, compares this list to previous users of the room, identifies the team and the project discussed at the last meeting. If the team wants to, the room configures itself restoring the state of the last meeting including the set of documents they were working on before. The content and the structure of the information is displayed again on the different roomware components (e.g., the interactive wall, the interactive table). Thus, the team can continue right where they were at the end of the last meeting.

A generalization of this idea results in what we call *attentive, active, and adaptive rooms or environments* (A^3*-environments).* "Attentive" means that the environment is able to observe a room, a hallway or another area of the building it is assigned to. It will be able to identify and locate people by various means (e.g., active badges, image recognition, video analysis). The same is possible for tagged and/or networked devices, e.g., the roomware components. Being informed about who and what is where and what is going on, the A^3-environment can be "active" by (re)acting in correspondence with predefined rules, e.g., providing information that there is a prepared agenda for the current meeting, that a team member who attended the last meeting is not present, etc. Furthermore, it can be “adaptive” by configuring the whole room or part of it according to context information on what the room should be used for, e.g., displaying the work environment of a specific project team. A^3-environments are adaptive in the sense of auto configuration but they can also be adapted by the user or the team. In both cases, the same room (or hallway, foyer, etc.) can be orchestrated for multiple purposes providing interactive information landscapes for changing usage conditions.

4 i-LAND: An interactive Landscape for Creativity and Innovation

In order to test the feasibility of the concept of a cooperative building, the i-LAND project was initiated. Its overall goal is to develop a work and collaboration environment which responds to the demands of new work practices and organizational innovation as they are characteristic for ad hoc and on demand teams, multiple-purpose use of project-team rooms, etc. Besides the overall goal, i-LAND serves as a testbed for the development of roomware and A^3-environments and their tailorability to specific requirements of potential user groups. It will also provide the basis for evaluating the ideas and concepts by applying them to a specific application scenario, i.e. the support of so-called creative teams. Examples are teams designing a new product, developing a marketing strategy for an existing product, developing a perspective on the future strategy of a company, etc.

4.1 Motivation and Requirements

The importance of supporting different work phases, e.g., involving subgroups as in the second scenario, has been shown in several empirical studies we conducted to evaluate our meeting support systems (Streitz *et al*., 1994). On the one hand, we found that certain features of the software – in our case the provision of hypermedia functionality – facilitates the division of labor in team work and resulted in better results in group problem solving (Mark *et al*., 1995, 1996). On the other hand, we investigated the role of different personal and public information devices (networked computers, interactive whiteboard) and different combinations of them for meeting room collaboration in a recent empirical study (Streitz *et al*., 1997). The results show that the groups which developed a balanced proportion of individual work, subgroup activities, and full team work achieved better results than those groups which stayed most of the time in the full-team work configuration. The degree of flexibility to work in different modes was largely determined by the combination of information devices provided to the team. Offering a wider range of devices or roomware components resulted in more flexibility.

While these encouraging results were obtained in existing electronic meeting rooms, these constellations do not provide the necessary flexibility of assigning different physical workspaces within a meeting room to subgroups and individuals. Existing electronic meeting rooms usually employ one large static table and computers on top of it or mounted in the table as we also did in the past (Streitz *et al.,* 1994). Thus, it is not possible to allocate and (re)configure the resources in terms of information objects/spaces, roomware components in a flexible way. This flexibility is a design goal of high priority for the i-LAND environment.

This design goal also requires to develop new means of distinguishing between individual and (sub)group work modes and using the detection of behavior and actions in the real world instead of setting parameters via complicated interfaces for initiating and terminating computer-supported cooperation (e.g., sharing of information) between people. The spatial flexibility and mobility of the roomware components requires the use of wireless networks for connecting the information devices embedded in the room and in the furniture and an independent power supply.

The current application scenario for i-LAND is to serve as a collaborative work environment facilitating especially creativity and innovation processes in teams. In order to inform our design and to tailor the generic components to this purpose, we are investigating specific requirements in terms of appropriate roomware components and creativity techniques supporting these processes. To this end, we are conducting an empirical study involving interviews of creative teams in selected companies in Germany. These teams are concerned with product design, marketing campaigns, strategic future planning, etc. We are describing and analyzing their current work practices using existing rooms, furniture, equipment, and creativity techniques. On this basis, we identify shortcomings of conventional practices and equipment. Furthermore, we are interviewing these teams about their requirements for support of creative collaborative work in the near future but inquire also about their fantasies and visions for the far future.

4.2 Roomware components of i-LAND

We defined an initial set of roomware components which will be described in detail in the following subsections:

- *DynaWall* **-** an interactive electronic wall
- *CommChairs* – mobile and networked chairs with integrated interactive devices
- *InteracTable* – an interactive table.

In addition, to bridge the real world and the virtual world we are designing a mechanism for establishing relations between real objects and information objects. We call this mechanism *Passage.*

While each category of the roomware components has a value of its own, the full benefit will only be available in their integration and combined use corresponding to the different work phases identified before. This is achieved via the integration of the roomware components in an application, in this case the i-LAND scenario. The technical integration is achieved by employing wireless networks connecting all components as well as by a client-server software based on the cooperative hypermedia framework COAST (Schuckmann *et al.,* 1996). Figure 3 shows our plan for the i-LAND environment.

The roomware components of i-LAND have been or are being built. The software providing the required functionality is still under development. Therefore, one has to keep in mind, that not all features described are already implemented in full but are part of the concept and the requirements for the components.

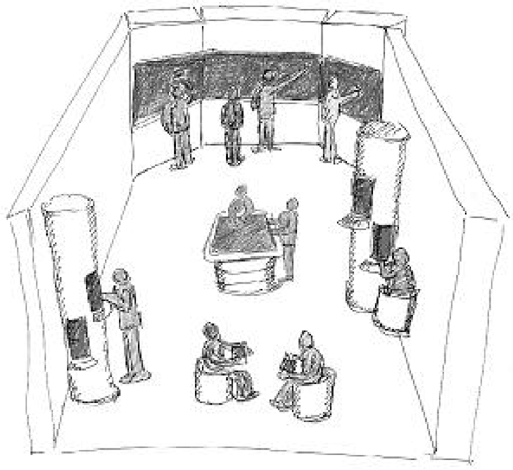

Fig. 3. View of the planned i-LAND environment showing three subgroups and two individuals.

4.2.1 DynaWall

Project teams in so-called project rooms often use large areas of assembled sheets of paper (usually covering the walls) to create and organize their information. Examples are large project overviews in terms of its parts, their relationships and dependencies. However, the need for large visual areas is not restricted to the organizational aspect. In many cases, even more important is the possibility for displaying, annotating and editing large contents which is not without problems, especially in the paper-based situation. Display space on paper or via an electronic information device is a crucial point for most visually-oriented tasks.

Furthermore, in the electronic version the requirement is to be able to interact with the content in a very intuitive way relying on standard gestures known from the interaction with the physical objects in the real / paper world.

The objective of the DynaWall is to represent a computer-based device that serves these needs. It can be considered an “interactive electronic wall” represented by a touch-sensitive information device. The current realization in the AMBIENTE Lab at GMD-IPSI uses three rear-projection interactive whiteboards (SMART Boards™) with a total display size of 4.5 m width and 1.1 m height and a resolution of 3072 by 768 pixels. It fills one side of the room completely (see figure 4). The DynaWall enables groups like project teams to display and to interact with large information structures collaboratively. The goal is to support two or more persons, either individually, in parallel or sharing the whole display space.

The size of the DynaWall creates a new set of problems for human-computer interaction. It should be possible that information objects can be taken at one position and put somewhere else on the display or thrown from one side to the opposite side. Dialog boxes always should appear in front of the current user(s). User interface components should always be at hand, etc.

Fig. 4. Two CommChairs in front of the DynaWall.

4.2.2 CommChairs

The CommChairs (see figure 5) represent a new type of furniture. They combine the mobility and the comfort of armchairs with high-end information technology.

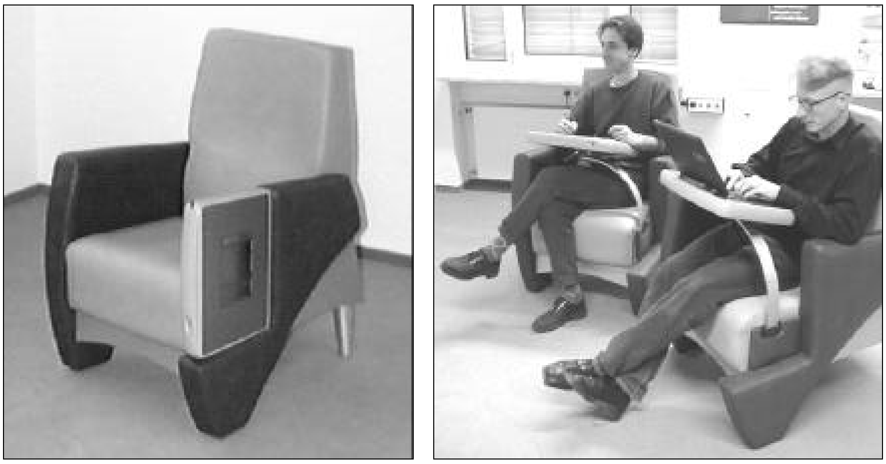

Fig. 5. CommChairs and their usage.

So far, we developed two variants: one with an integrated information device and one with a docking facility for plugging in laptops or other mobile computers carried along (figure 6).

Fig. 6. left - CommChair with integrated pen-based computer,
right - CommChair with docking facility for standard laptops.

Each chair is provided with an interface for wireless networks and an independent power supply for maximum flexibility and mobility. We use a radio-frequency network for connecting to the Ethernet. Because of this connection, one can access world-wide information while sitting in the chair.

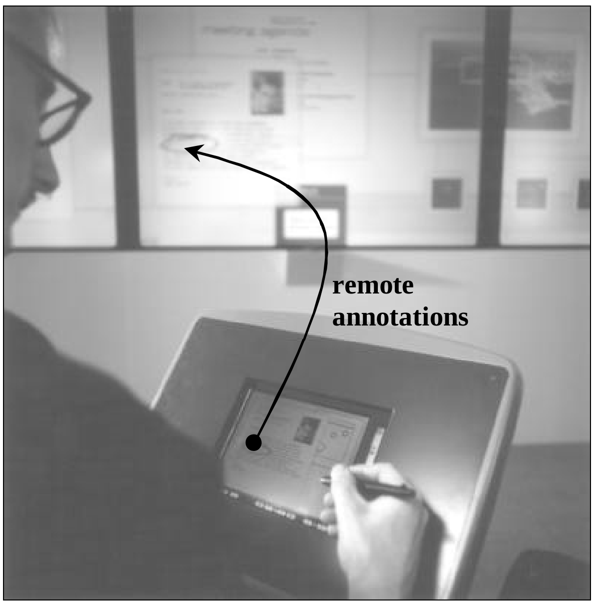

Fig. 7. Accessing the DynaWall from the CommChair.

Furthermore, the chairs enable people to make private annotations and notes and to connect to shared workspaces, displayed on devices like the InteracTable or the DynaWall. Users can edit and annotate objects displayed on these roomware components not only locally but also remotely (figure 7).

Localization of the chairs in a room and the identification of the person sitting in the chair will be done automatically based on sensors we will provide in the room. This allows to bring up and configure the personalized environment. Furthermore, this enables also to establish network connections and then shared information displays simply by moving chairs together.

Built-in audio and video communication facilities, leaving messages for other people sitting in that chair as well as tactile notification of incoming calls/information are further aspects that are planned in this part of the i-LAND project.

4.2.3 InteracTable

The InteracTable is the first in a series of information devices that investigates general shapes and orientations of interaction areas. It is designed for display, discussion, and annotation of information objects by a group of two to six people sitting or standing around the table.

The current stand-up version of the InteracTable (figure 8) is built as a vertical rear-projection unit with a touch-sensitive display surface. Inside the table, an LCD beamer projects a high-resolution image of 1024x768 pixels to the top of the table. The integrated wireless network provides the InteracTable with a high degree of flexibility.

Fig. 8. Informal discussion at the InteracTable.

Since a round or oval-type display has no selected orientation as, e.g., top and bottom and left and right at the desktop computer, one has to provide new means of interaction. Information objects displayed on the table have to be rotated and shuffled across the surface in correspondence to different view perspectives of the users standing or sitting around the table. Manipulation is done by gestures using fingers or pens, annotations by voice and/or pen. In addition, an infrared keyboard is available for more extensive text-entry tasks.

4.2.4 Passage

Transportation of complex information structures collected from various sources very often is an awkward task: numerous tools have to be started, the material has to be arranged, maybe copied, and finally sent to the new location, e.g., by e-mail attachments, ftp or similar services. When the person that sends this information arrives at the new location, a similar activity of unpacking the material begins. The idea of Passage describes an elegant mechanism of connecting information structures in the digital, virtual world of computers with a real-world object. Such a detectable object, we call it a *Passenger,* can be seen as a physical bookmark into the virtual world. One can connect information to it, take it, carry it physically to the new location, e.g., in the pocket of a shirt, and simply by putting it on a special device called *Bridge*, the information is displayed immediately. It is no longer necessary to open windows, browse hierarchies of folders, worry about mounted drives and doing similar annoying actions. Passage is a concept for ephemeral binding of content to an object.

A Passenger does not have to be a special object. Any uniquely detectable object may become a Passenger. Since the information structures are not stored on the Passenger itself but just linked to it, people can either turn personal objects into a Passenger, like a watch, ring, or glasses, or they can use objects that are neutral in terms of personal value. In the current i-LAND scenario, we use small wooden building blocks of different size, shape and color that are inexpensive and can be bought in every toy store. The only restriction Passengers have is that they can be identified by the hardware and the software of the Bridge and that they are unique.

The connection between an information structure and an object is established by making use of a Bridge device (see the tray in the middle of the DynaWall shown in figure 4). A user simply puts an object on the Bridge, selects the material to be transported on the screen and activates a widget that links this material to the object, turning it into a Passenger. At the same time, the Passenger is registered in a central repository of valid Passengers. When such a Passenger is carried to and put on another Bridge, its software, which has access to the repository via the computer network, recognizes the Passenger, collects the material, mounts network drives if necessary and finally displays the information on the screen that is connected to the Bridge. By using another widget, a Passenger retires, i.e. the connection between the object and the information is removed. As a first approach and just for demonstration purposes, we implement the Bridge as a scale with fine granularity that is connected to a computer via the serial port. Our sample Passengers, the small wooden building blocks, all have a different weight, and are uniquely identifiable.

5 Related Work

The roomware concept, the development of different roomware components as instantiations of this concept and their integration in the i-LAND environment is related to and was inspired by different developments in human-computer interaction and computer-supported cooperative work. The most relevant examples are augmented reality, ubiquitous computing, and collaborative workspaces, in particular meeting support systems. One perspective is that we develop new ideas for human-computer interaction and apply them to the design of collaborative work environments. A complementary perspective is that we extend interaction techniques by cooperative functionality in order to develop ubiquitous and collaborative workspaces.

5.1 Augmented Reality

Augmented reality can be viewed as the counter-approach to artificial or virtual reality. It is concerned with the use of computational devices in order to augment our perception and interaction in the physical world. The devices that add computational information to the appearance and/or use of reality can take various forms. For an overview of initial work see Wellner *et al*. (1993). Examples are the DigitalDesk that uses a video projection of a computer display as an overlay on paper documents on a real desk (Wellner, 1993), the Chameleon prototype consisting of a small portable, display and spatially-aware palmtop computer that can act as a window into the information space (Fitzmaurice, 1993), and the NaviCam (Rekimoto & Nagao, 1995) providing context-sensitive information about objects in the physical environment via a palmtop displaying combined video images and data.

In comparison to the DigitalDesk, the InteracTable provides a touch-sensitive interactive display and is not using an overlay of video projections. With respect to NaviCam or Chameleon, we currently do not plan to develop special devices that add computational information to the visual appearance of reality. Instead, in the roomware concept, everyday objects as, e.g., furniture are augmented with computational functionality in order to add value with respect to cooperation support.

A related approach to augmented reality is the notion of tangible bits and ambient media (Ishii & Ullmer, 1997). It is based on the idea of graspable user interfaces (Fitzmaurice *et al*., 1995) where a physical "brick" can be used to manipulate a virtual object. Tangible bits was also inspired by the "marble answering machine" developed by Bishop (see Poynor, 1995) where incoming phone calls are indicated by (physical) marbles which can be placed on a specific area for playing the message. While these interfaces are concerned with foreground activities of users, ambient displays – realized as elements in the periphery of the architectural space – provide interfaces to background information (Ishii & Ullmer, 1997).

Our "Passage" mechanism is also inspired by the "marble answering machine" but it extends this idea by using physical objects not only as representatives for digital information but also as means for physical transport of information between different roomware components, e.g., the DynaWall and the InteracTable.

5.2 Ubiquitous Computing, Multiple Devices

Pursuing the approach of augmented reality seriously implies to have many, loosely spread and networked information devices around, with displays of different sizes, instead of a (central) desktop computer. This is the concept of ubiquitous computing (Weiser, 1991, 1993) and – in a related way - of ubiquitous media (Buxton, 1997). Some of the devices will stand out and be recognized as computers, others will be "invisible" as they are embedded in the environment. Our roomware approach concentrates especially on integrated devices that are embedded in furniture, like chairs and tables, as well as in architectural elements of buildings, such as doors or walls.

Once the physical space is filled with multiple devices, the issue arises on how to transfer information between them in an intuitive and direct way and, more general, how to interact with them. This problem is addressed, e.g., by the "pick-and-drop" technique (Rekimoto, 1997, 1998 in this volume). We address these challenges by a similar technique called "take-and-put"; furthermore by throwing and shuffling of information objects, especially on large displays, and by our "Passage" concept for the physical transportation of information.

5.3 Collaborative Workspaces

With respect to existing work in computer-supported cooperative work, especially meeting support systems as, e.g., CoLab (Stefik *et al.*, 1987), GroupSystems (Nunamaker *et al.*, 1995), ShrEdit in the CREW Lab (Olson *et al.*, 1993), Tivoli (Pederson *et al.*, 1993), and our own previously developed DOLPHIN system in the OCEAN Lab (Streitz *et al.*, 1994, 1997), our new approach is different because of the notion of dynamic offices and mobile roomware components. This allows flexible and dynamic creation and allocation of workspaces in different parts of a room in correspondence with the current mode of the group activity instead of having a fixed setup of chairs around a static table. It enables new methods of establishing cooperation and sharing of information, e.g., by simply moving chairs in close spatial proximity in order to form a subgroup. Thus, initiating cooperation between two or more people can be based on an intuitive and natural physical movement instead of selecting parameters in a number of menus and dialogue boxes.

Other relationships concern the type of work supported and the type of software used for this support. With respect to supporting creative work, the most common technique is brainstorming. It has been demonstrated that computer-supported brainstorming results in more number of ideas than verbal brainstorming. One reason among others is that the possibility of parallel input decreases production blocking (Gallupe *et al.*, 1991). GroupSystems (Nunamaker *et al.*, 1995) and ShrEdit (Olson *et al.*, 1993) are examples of systems supporting brainstorming.

There are limitations with existing systems we like to overcome. We will provide a suite of creativity techniques which can be combined in a flexible and seamless way. Furthermore, existing systems are usually limited to text items. Another issue is the flexibility of the available structures in order to overcome the limitations of more or less flat or hierarchical list structures. This will be partially based on our previous work by using hypermedia structures for the underlying representation (Streitz *et al.*,

1994) but we will complement it by new concepts. Therefore, as part of our approach in i-LAND, we plan to develop new visualization metaphors for presenting content and structures of our “interactive landscape for creativity and innovation”.

6 Conclusions and Future Work

We have presented a comprehensive approach for the integrated design of real architectural spaces and virtual information spaces. The central idea is the concept of roomware components facilitating interactive and cooperative functionality at every place in a cooperative building. This paper described the current state of the design considerations, the first realization of roomware components and the requirements for the software currently under development.

Since the described components of i-LAND introduce new, to some degree unfamiliar forms of human-computer interaction, there is a need to evaluate their usefulness and their usability in a systematic fashion. Since i-LAND offers various configurations and combinations of the components, we have to evaluate also how to match different cooperation scenarios with different roomware configurations and to investigate their influence on the work processes. This evaluation effort is an important aspect of our iterative design cycle.

For updates of the work on i-LAND and related activities in the AMBIENTE Division at GMD-IPSI, please visit our website: http:// www.darmstadt.gmd.de/ambiente/

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