25

Roomware: Toward the Next Generation of Human-Computer Interaction Based on an Integrated Design of Real and Virtual Worlds

Norbert A. Streitz
Peter Tandler
Christian Müller-Tomfelde
Shin'ichi Konomi

25.1 Introduction

The next generation of human-computer interaction (HCI) is determined by a number of new contexts and challenges that have evolved during the last five to ten years and will be evolving more rapidly in the next five to ten years. They are rooted in new, emerging technologies as well as in new application areas asking for new approaches and visions of the future beyond the year 2000. It is not the intention of this chapter to give a comprehensive account of all relevant new contexts. We focus on selected areas complementing other contributions in this book. There is no doubt that new developments in the fields of multimedia, hypertext/hypermedia (especially in their popular versions as World Wide Web-applications), three-dimensional representations, and virtual reality technology will have a great impact on the type of issues HCI has to address and on how interfaces will look in the future.

Taken those developments as given, we present an approach and a framework that—at least so far—has not become a mainstream orientation for guiding design and development of the next generation of human-computer interaction. We are aware of the fact that there are related attempts, and we describe them. Nevertheless, there is still an indispensable need for a comprehensive framework. According to our view, the following four areas have to be integrated into an "umbrella" framework:

Computer-Supported Cooperative Work (CSCW), Ubiquitous Computing (UbiCom), Augmented Reality (AR), and Architecture. Note that in this chapter we use the term *architecture* primarily in the sense of real, physical environments—like rooms and buildings—and not in the sense of system architecture or software architecture. These areas are not an arbitrary list but rather the necessary constituents for a framework of designing HCI in the future. Their mutual relationships and dependencies are shown in Figure 25.1.

25.1.1 CSCW

User-interfaces used to be interfaces for single-user applications; now, most applications are multi-user applications supporting cooperative work. This means that user-interfaces have to be built in such a way that they always indicate if people are either working alone, in one of several possible subgroup constellations, or with all members of their team or organization. The interfaces will provide intuitive ways of sharing information synchronously as well as asynchronously. People will be able to move smoothly between the different configurations without having to change applications.

25.1.2 Ubiquitous Computing

While in the past there was a central mainframe computer with terminals for many users, the age of the personal computer follows the guideline of one person and one computer. Now we are moving into an era where one person will have *multiple devices* available in his or her environment. Computational power will be available everywhere, will be ubiquitous, or *ubiquitous computing* (Weiser 1991). People will view and use many of them as rather specialized *information appliances* (Norman 1998). Our extension of this view is that multiple devices are not only available to individuals but to groups. Thus, the cooperative nature of multiple devices will be

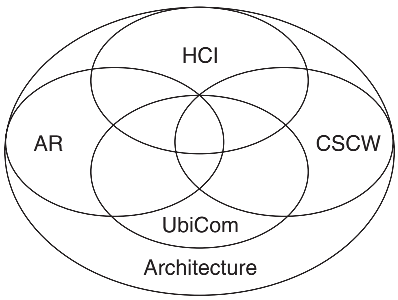

FIGURE 25.1 Our view of the contexts of the future of HCI

more in the foreground than it is currently. The devices are networked in several ways (more and more wireless), allowing to share information between them. People will use them in parallel as individuals as well as in groups. These devices will differ in their characteristics—for example, in terms of size from very small (palm size) to very large (wall size). They will also differ in terms of the functionality they provide in local as well as in distributed settings.

25.1.3 Augmented Reality

In contrast to virtual reality, there are conceptual and technological developments emphasizing that the objects of the real environment should and can be augmented instead of diving into "cyberspace" or immersing into "virtual reality." *Augmented reality* is the result of overlaying and adding digital information to real objects or integrating computational power into them (Wellner et al. 1993). The importance of "tangible bits" conveyed by real objects (Ishii and Ullmer 1997) is a related approach. This direction will be even more relevant in combination with the next area: the architectural environment around us.

25.1.4 Architecture

Finally, HCI and the preceding areas have to be aware of the importance of the real world—that is, the physical, *architectural space around us* in which people interact with the devices. For many HCI applications in the future, the space is constituted by buildings with their range of offices, meeting rooms, cafeterias, hallways, stairways, foyers, gardens, and so on, thus going far beyond the traditional desktop setting. This motivates a more explicit relationship to the field of *architecture.* Our view is that the physical space around us provides rich affordances for interaction and communication that should be exploited. Research in HCI has neglected this larger context by limiting itself for a long time to the desktop computer. More recently, these issues are now being addressed, such as with the notion of cooperative buildings (Streitz et al. 1998a).

We will elaborate on the role of these areas to HCI in more detail as we go along, presenting the design rationale for the development of what we call "roomware" as the constituents of so called "Cooperative Buildings." By *roomware®,* we mean computer-augmented objects resulting from the integration of room elements, such as walls, doors, or furniture with computer-based information devices. Their characteristics require, and at the same time provide, new forms of human-computer interaction and of supporting cooperative work or, more general, cooperative experiences and activities. With *Cooperative Buildings,* we indicate the overall conceptual framework as well as its concrete realization in terms of the envisioned architectural envelope with integrated ubiquitous IT components resulting in smart artifacts so that the world around us is the interface to information and for cooperation. In these settings, traditional *human-computer* interaction will be transformed to *human-information*-interaction and *human-human* communication and cooperation.

The chapter is organized as follows. In Section 25.2, we present three points of departure determining the requirements and challenges for the next generation of human-computer interaction. Related work and technologies are described in Section 25.3. Section 25.4 and 25.5 introduce the basic concepts of our approach: Section 25.4 describes four design perspectives for the workspaces of the future; Section 25.5 introduces the overall framework of "cooperative buildings." Section 25.6 complements the conceptual analysis with requirements taken from an empirical study. Section 25.7 describes the implications for designing new forms of human-computer interaction and cooperation in terms of the "roomware" components and their realization as part of the i-LAND environment. Section 25.8 and 25.9 provide the description of the network infrastructure and the BEACH software. Final conclusions are given in Section 25.10.

25.2 Three Points of Departure

In this section, we present three areas as points of departure in order to determine important requirements for the next generation of human-computer interaction: information and communication technology, work practice and organization, and the architectural setting of the real world around us.

25.2.1 Information Technology: From the Desktop to the Invisible Computer

The introduction of information and communication technology caused a shift from the physical environment as the place for information objects to desktop displays as *the* interfaces to information. In the traditional office environments of the past, information objects were themselves physical objects: paper documents such as books, memos, letters, calendars in the office, announcements on bulletin boards in hallways, flip charts, and whiteboards in meeting rooms. They were created, accessed, and manipulated in a straightforward way via physical operations with appropriate tools and very little overhead. Although the "paperless office" did not become a reality and probably never will, these physical information objects have been replaced to a large degree by digital information objects such as electronic documents. Large and bulky monitors sitting on desktops and being connected to a PC tower under the table became the standard computer equipment in our offices today. Desktop displays became the "holy" entrance to "cyberspace" as the virtual place where one finds information.

As a result, the main focus of research and practice in human-computer interaction was and still is concerned with the issues of designing, creating, and using virtual information spaces to be displayed on desktop computers. But is human-*computer* interaction really the goal? Isn't it human-*information* interaction and human-*human* interaction and cooperation? Shouldn't we get rid of the computer as a device in the foreground? Similar to driving a car and not thinking about the underlying machinery and the fact that one is (at least in modern cars) interacting with 20 or more microprocessors and computers, one should be able to interact with information in an intuitive way and be able to cooperate with other people. The basic underlying idea was expressed by Mark Weiser (1991) in the following way.

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

This vision, although addressed many times in the past, has become again a major concern in recent years. Technology should be moved to the background and turn into "calm technology" where the interface will be invisible (Weiser 1998). The computer will be "invisible"—for example, when using information appliances that are "hiding the computers, hiding the technology so that it disappears from sight" (Norman 1998). We have adopted this perspective but extended it in various directions to be described in the main part of the paper.

25.2.2 Organization: New Work Practices and Team Work

The introduction of information technology in the workplace did not only change the contents of work but also the work processes. These changes effect the organization of work in the office (desk sharing is an example) as well as the place of work. Working from home (telework) or in the hotel, on the train, on the plane, or at the customer's site (mobile work) results in a higher degree of transitions between individual work "on the road" and collaborative work at the office (for example, group meetings) and between asynchronous and synchronous work. In parallel, new organizational forms have changed the business world based on new developments in management sciences and business process (re)engineering efforts. Organizations adopt process and customer-oriented business models resulting in more flexible and dynamic organizational structures. A prominent example is the creation of ad hoc and on demand teams in order to work on a project for a given period of time, solving a specific problem.

On demand and ad hoc formation of teams requires powerful methods and tools for the support of different work phases in teams. When evaluating the meeting support systems we have developed in the past (Streitz et al. 1994), we found in one of our empirical studies (Mark et al. 1997) that the provision of hypermedia functionality facilitates the division of labor in team work. This resulted in better results in the group problem-solving activities. Furthermore, 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 another empirical study (Streitz et al. 1997). These results show that groups with a balanced proportion of individual work, subgroup activities, and full team work achieved better results than those groups that 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 range and combination of information devices provided to the team.

25.2.3 Architecture: The New Role and Structure of Office Buildings

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. It is time to reflect these developments not only in terms of new work practices and use of information technology but also in the design of the physical architectural environment so that the workspaces of the future will be equally dynamic and flexible. While the introduction of information and communication technology has already changed the content of work and work processes significantly, the design of the physical work environments such as offices and buildings has 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. This is especially true for the issues related to mobile work. If, in principle, one can work anytime anyplace, one could ask the challenging questions "Why do we still need office buildings? Aren't they obsolete given the possibilities of modern mobile technology?"

It is our point of view that office buildings are still of high value but that their role will change—*must* be changed. They will be less the place for individual work and more the space for planned team work and group meetings as well as for a wide range of social interactions, such as spontaneous encounters, informal communication, and unplanned opportunistic cooperation. We are also convinced that social interactions in co-located settings, as in buildings, are becoming increasingly important for establishing a corporate identity, group feeling, and trust, because teams with changing team members and changing tasks are established at much higher rates than before.

These considerations are the starting points for our framework of *cooperative buildings* (Streitz et al. 1998a). They have to be designed as flexible and dynamic environments that provide cooperative work and experience spaces supporting and augmenting human communication and collaboration.

25.3 Related Work

As indicated earlier, we are trying to offer a comprehensive framework integrating a wide range of approaches. Thus, there are a number of developments that have influenced our thinking. Due to the limitations of space, we concentrate here on two areas of recent developments that are especially relevant: augmented reality and ubiquitous computing. We selected those because they best reflect one of our central beliefs that the real world around us should be the starting point for designing the human-computer interaction of the future. We are also aware that there is a large body of research in the area of CSCW on which we are building, especially work on electronic meeting rooms and/or interactive whiteboards where we also contributed (Stefik et al.

1987; Pederson et al. 1993, Olson et al. 1993; Streitz et al. 1994; Nunamaker et al. 1995; Schuckmann et al. 1996). Due to lack of space, we decided not to describe this work in more detail. For an overview of CSCW, see Baecker (1993). Augmented reality can be understood as the counterpart to virtual reality. Rather than wearing goggles or helmets in order to immerse in a virtual world, augmented reality is concerned with the use of computational devices in order to augment our perception and interaction in the physical world. For an overview of initial work, see Wellner et al. (1993). A well-known example is the DigitalDesk that uses a video projection of a computer display as an overlay on paper documents on a real desk (Wellner et al. 1993). A project that uses front projection techniques is The Office of the Future (Raskar et al. 1998). It is based on computer vision and computer graphics technology utilizing spatially immersive displays (SID's) in order to surround users with synthetic images. Their vision is that "anything can be a display surface," whether it be a wall or a table. Even objects with irregular shapes can be used. Their major application is to build systems for shared telepresence and telecollaboration. Other examples of augmented surfaces were developed by Rekimoto and Saitoh (1999), for creating hybrid environments, and the ZombieBoard by Saund (1999). In order to extend the channels of perception and make use of peripheral awareness, so called "ambient displays" have been proposed. A well-known example is the ambientROOM (Wisneski et al. 1998) where, for example, water ripples are projected on the ceiling of a room to indicate different activities.

Another direction is the notion of "graspable" user interfaces with "bricks" (Fitzmaurice et al. 1995) and "tangible bits" (Ishii and Ullmer 1997). This work was also inspired by the "marble answering machine" developed by Bishop (Poynor 1995), where incoming phone calls are indicated by (physical) marbles that can be placed on a specific area for playing the message. We will come back to this idea when we describe our Passage mechanism (Konomi et al. 1999) in Section 25.7.6. Related to this approach is the mediaBlocks system (Ullmer et al. 1998). It uses electronically tagged blocks to store, transport, and sequence online media. Although they realize a certain degree of simplicity and "lightweight" mode of operation, "mediaBlocks" have to be specially crafted before the system is used and can be inserted into dedicated slots.

Ubiquitous computing is in some way a direct consequence when pursuing the approach of augmented reality seriously. It requires having many, loosely spread and networked information devices around, with displays of different sizes, providing functionality everywhere instead of only at the desktop computer. This is the concept of ubiquitous computing (Weiser 1991) and ubiquitous media (Buxton 1997). The size of these devices can range from very small to very large. Some of the devices will stand out and be recognized as computers; others will be "invisible" as they are embedded in the environment. Once the physical space is filled with multiple devices, two sets of issues come up. First, how can you transfer information between them in an intuitive and direct way, and, more generally, how can you interact with them? Second, it is desirable to know the position of the devices and their state wherever they are in a room or a building. The first issue is addressed by the "pick-and-drop" technique (Rekimoto 1997, 1998), and our concepts of "take-and-put" and

"Passage" (Konomi et al. 1999) are described in Section 25.7.6. The second issue requires setting up an infrastructure of sensing and localization technology that determines where the devices are and where users are performing their tasks. (We know this raises a number of controversial issues with respect to privacy considerations, but they are beyond the scope of this paper.)

25.4 Design Perspectives for the Workspaces of the Future

In our vision of the workspaces of the future, we believe *the world around us will be the interface to information,* represented via ubiquitous devices, some visible and others "invisible," in the sense that they are embedded in the physical environment. We anticipate a situation where people interact with each other in ubiquitous and interactive landscapes for interaction and cooperation augmenting our real environments.

In order to develop the workspaces of the future, we follow a human-centered design approach (see Figure 25.2). Since the human is at the center, we first must

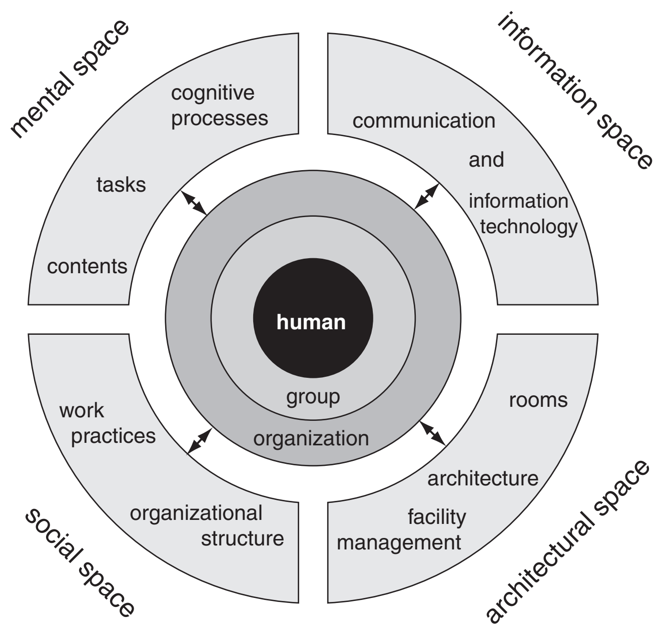

FIGURE 25.2 Four design perspectives for the work spaces of the future

address the *mental space*—considering the potential and the limitations of the human processing system and the individual's cognitive processing of content and tasks. The perspective of designing the *information space* represents the mapping of tasks and contents on corresponding and compatible representations of the information system realized as software and hardware. Human problem-solving activities are mapped on corresponding ways of human-computer interaction and mediated by networked information devices providing the functionality needed for working on the task. However, the human is part of a group or a team, and the team has to be viewed in the context of an organization. This requires consideration of the *social space,* which reflects the role of different work practices and organizational context in the design of corresponding cooperation and communication technology. This is (in a way) the CSCW perspective. Finally, we have to take into account the *architectural space* reflecting the characteristics of the rooms and other architectural components of the building. It is obvious to us that physical objects and their placement in the architectural space provide valuable "affordances" for organizing content information and meta information for the activities of individuals as well as groups.

In summary, we have to consider all four design perspectives or spaces shown in Figure 25.2 where the implicit distinction between real and virtual worlds plays a special role. Although we will come back to this, we want to emphasize here that we argue for a two-way augmentation and smooth transitions between real and virtual worlds. Combining them in an integrated design allows us to develop enabling interfaces that build on the best affordances of everyday reality and virtuality in parallel. As designers of human-computer interaction, or rather human-information interaction, and human-human cooperation, we want to use the best of both worlds.

25.5 Cooperative Buildings

Due to the new role of office buildings in the future, one has to reflect this in the overall design of the workspaces of the future. To this end, we proposed the concept of *Cooperative Buildings* in Streitz et al. (1998a) and established also a series of International Workshops on Cooperative Buildings (Streitz et al. 1998b, 1999b). We used the term *building* (and not *spaces*) to emphasize that the starting point of the design should be the real, architectural environment: Even a person navigating in the chat rooms of cyberspace is sitting somewhere in the real space. By further calling it a "cooperative" building, we wanted to indicate that the building serves the purpose of cooperation and communication. At the same time, it is also "cooperative" toward its users, or rather, inhabitants and visitors, by employing active, attentive, and adaptive components. In other words, the building not only provides facilities but it also (re)acts "on its own" after having identified certain conditions. It is part of our vision that it will adapt to changing situations and provide context-aware information according to knowledge about past and current states or actions and, if available,

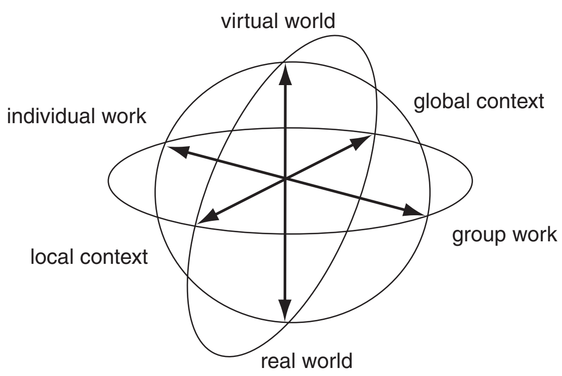

FIGURE 25.3 Three dimensions of cooperative buildings

even about plans of the people. The three dimensions, shown in Figure 25.3, are useful to structure the requirements for the design of cooperative buildings.

First, we address the *"real world 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 use them here more or less interchangeably. Our day-to-day living and working environments are highly determined by the physical, architectural space around us constituted by buildings with walls, floors, ceilings, furniture, and so forth. They constitute also rich information spaces due to the inherent affordances either as direct information sources (such as calendars, maps, charts hanging on the walls, books and memos lying on the desks) or by providing ambient peripheral information (such as sounds of people passing in the hallway). Furthermore, nonplanned encounters of people at the copying machine, in the commons, or in the cafeteria are rich opportunities for the exchange of information, either social or task- and goal-oriented.

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. In a cooperative building, we augment therefore the informal interaction spaces in addition to the "official" meeting rooms with information technology, so that people can create, retrieve, and discuss information in a ubiquitous fashion. This requires an integration of information spaces and a means of interacting with them in the physical environment, such as walls and furniture (this results in "roomware"—see Section 25.7).

There is another aspect of the "virtual" part of this dimension. People are not only in one physical location but in remote, distributed locations. Associated terms are virtual meetings, virtual teams, and virtual organizations. 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 traveling salesperson. 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 is in line with the work on media spaces (Bly et al. 1993) and ubiquitous media (Buxton 1997). If one goes beyond standard desktop videoconferencing, one is faced with challenging design issues for creating a "shared" background setting in which the distributed members are placed (Buxton 1997). Further issues of distributed rooms coupled via videoconferencing are addressed by Cooperstock et al. (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 synonymously with colocated, 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 "nearby" or a remote place? Does the notion of remote location and global context start in another building, another city, or another continent? Using sensors for determining positions facilitates that the information devices know where they are and what their local and global context is. In this way, the cooperative building can be provided with information about the location of people in relationship to the devices. At a more general level, the local vs. global dimension addresses also the differences in social contexts of work arising from different organizational structures, either working in a local team or with other organizational units of a global organization, like a multinational company.

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 groupware (Streitz et al. 1994). 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, and so on.

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. In our ongoing work of developing the i-LAND environment (see Section 25.7.1), we concentrate especially on two of the three dimensions discussed in the previous section: the real vs. virtual and the individual vs. group dimension.

25.6 Requirements from Creative Teams

While innovative concepts and visionary scenarios as well as advances in basic technologies are important to make progress, we know from the principles of user-centered and task-oriented design that this is not sufficient for the development of new systems. In order to inform our design, we conducted an empirical study investigating the current work situation of teams and their requirements for future environments. Due to limited space, we report only selected results of the study (Streitz et al. 1998c).

We selected five companies from the automobile and oil industry and in the advertising and consulting business. These companies were chosen because they had special groups called "creative teams" working in the areas of strategic planning, identifying future trends, designing and marketing new products, and so on. We interviewed representatives of the teams, visited the project and team meeting rooms, and distributed a questionnaire to all team members. The total number of people in these five teams was 80. They had academic education with various backgrounds: engineering, computer science, business administration, psychology, and design.

The results showed that the meeting facilities were in most cases traditional meeting rooms furnished with standard equipment like large, solid tables and chairs, flip charts, whiteboards, and overhead projectors. In only one case, there were a couple of computers, a scanner, and a printer permanently installed in the meeting room. No active creation of content during the meeting was done with the aid of computers. Different creativity techniques (brainstorming, Metaplan) were used but only in a paper-based fashion. The results on the current state were somehow contrary to our expectations because we had expected more (active) usage of computer-based technology in the meetings.

The situation changed when we asked about the requirements for the future. Usually, a large room was required with a flexible setup and variable components that would allow different configurations. The room should have the character of a marketplace or a landscape providing opportunities for spontaneous encounters and informal communication. The response (translated from German) was "Team meetings are not anymore conducted by meeting in a room but by providing an environment and a situation where encounters happen." The furniture should be multifunctional and flexible.

Although the current situation was rather low-tech, there was a great openness for computer-based support in the following areas.

- Information gathering while preparing meetings in advance by accessing internal and external databases
- "Pools of ideas"—also called "idea spaces"
- A wide range of creativity techniques where the computer-based version should allow for flexible configuration or tailoring of the underlying rules
- Presentation styles deviating from the traditional situation and involving the attendees in an active fashion labeled as "participatory presentation"
- Visualizations inspiring and enhancing the creative process
- Communicating and experiencing content via channels other than only visual: acoustic, tactile

There was less emphasis on videoconferencing than we expected. The teams stressed the importance of personal presence being essential for creating a stimulating and productive atmosphere. While computer-based support was strongly requested, the computer should stay in the background. As they explained (translated from German), "We have the creative potential, not the computers." In summary, the teams wanted to have much freedom in reconfiguring their physical environment and their information environment.

25.7 Roomware® Components

Our approach to meet the requirements of flexible configuration and dynamic allocation of resources in physical and information environments in parallel is based on the concept we call *roomware®*. By roomware, we mean computer-augmented objects resulting from the integration of room elements—walls, doors, furniture—with computer-based information devices. While the term roomware was originally created by Streitz and his Ambiente-Team (Streitz et al. 1997, 1998a) and is now also a registered trademark of GMD, it is also used for a general characterization of this approach and even products in this area.

The general goal of developing roomware is to make progress toward the design of integrated real architectural spaces and virtual information spaces. In the context of supporting team work, roomware components should be tailored and composed to form flexible and dynamic "cooperation landscapes" serving multiple purposes: project team rooms, presentation suites, learning environments, information foyers, and so forth. Also, all these goals involve the development of software that enables new forms of multi-user, multiple-displays human-computer interaction and cooperation. We will present examples as we go along.

25.7.1 The i-LAND Environment

On the basis of our conceptual and empirical work as well as integrating ideas from related work, we created a first visualization and description of the planned environment. Figure 25.4 shows the "vision scribble" in spring 1997. The environment is called i-LAND: an interactive landscape for creativity and innovation. On the one hand, i-LAND is a generic environment consisting of several roomware components that can be used in different ways. On the other hand, its development was also application-driven, especially in terms of the functionality provided by the BEACH software we developed for working with roomware (see Tandler 2000, 2001, and Section 25.9). The original vision scribble showed the following roomware types: an interactive electronic wall *(DynaWall®)*, an interactive electronic table *(InteracTable®)*, and mobile and networked chairs with integrated interactive devices *(CommChairs®)*. This was the initial set of the *first generation of roomware®* and was assembled in the AMBIENTE-Lab at GMD-IPSI in Darmstadt. Together with the BEACH software, this set constituted the first version of the i-LAND environment in 1997 and 1998. In 1999, we developed together with partners from industry—as part of the R&D consortium "Future Office Dynamics" (FOD 1999)—the *second generation of roomware®* where we redesigned the CommChairs® and the InteracTable® and developed a new component called *ConnecTable®*.

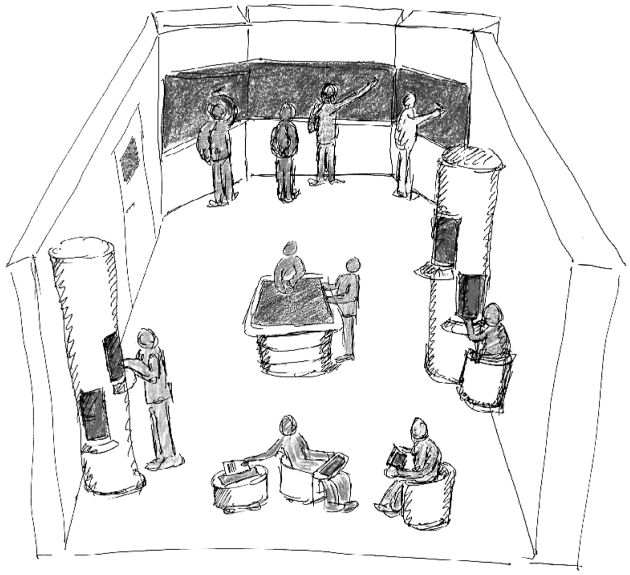

FIGURE 25.4 The vision scribble of the i-LAND environment in early 1997

In our vision scribble (Figure 25.4), we also suggested workplaces for individual work—for example, searching for background information—and called them "columns of knowledge." Furthermore, we think that there will be always paper in one way or the other. Thus, we suggested the mobile "ScanTable" as an integrated device for scanning paper documents so that the content is immediately available for further processing via the network on different roomware components, for example, to be shown and annotated on the DynaWall. Since the latter two components were not so innovative, we built—for the first generation of roomware—the previous three types initially mentioned. Although the focus was on designing workspaces for co-located teams, the i-LAND environment can easily be extended to provide support for global cooperation of distributed teams. Further information on i-LAND can be found in Streitz et al. (1999a). Now we give an overview of the different roomware components.

25.7.2 The DynaWall®

The objective of the *DynaWall®* is to provide a computer-based device that serves the needs of teams for cooperating in project and meeting rooms. It can be considered the electronic equivalent of large areas of assembled sheets of paper covering the walls for creating and organizing information. Teams are now enabled to display and interact with large digital information structures collaboratively on the DynaWall that can be considered an "interactive electronic wall." The current realization consists of three segments with back projections and large touch-sensitive display surfaces. The total display size of 4.50 m (15 ft) width and 1.10 m (3 ft 7 in.) height covers one side of the room completely (see Figure 25.5). Although driven by three computers, the BEACH software provides one large homogeneous workspace with no interaction boundaries between the segments. Two or more persons are able to either work individually in parallel or to share the whole display space.

The size of the DynaWall causes new challenges for human-computer interaction. For example, it will be very cumbersome to drag an object or a window over a distance of more than 4 m by having to touch the DynaWall all the time (similar to holding down the mouse button) while walking from one side to the other. Therefore, we have developed two mechanisms addressing these problems. Similar to picking up an object from a pinboard and place it somewhere else, our "take and put" feature allows us to "take" information objects at one position, walk over (without being in contact with the DynaWall), and "put" them somewhere else on the display. For bridging the distance between several closely cooperating people, "shuffle" allows us to throw objects (even with different accelerations) from one side to the opposite side where they can be caught and used by another team member.

The interaction of creating, moving, and deleting objects and their content is primarily gesture-based and does not require selecting different modes. This mode-less interaction is achieved by using the incremental gesture recognition provided by BEACH. (For more details see Tandler [2000, 2001] and Section 25.9).

FIGURE 25.5 Two people sitting in CommChairs cooperating with a person at the DynaWall (first generation of Roomware)

25.7.3 The CommChairs®

The *CommChairs*® (see Figures 25.5 and 25.6) are mobile chairs with built-in or attached slate computers. They represent a new type of furniture combining the mobility and comfort of armchairs with high-end information technology. The CommChairs allow people to communicate and to share information with people in other chairs, standing in front of the DynaWall or using other roomware components. They can make personal notes in a private space but also interact remotely on shared (public) workspaces—for example, making remote annotations at the DynaWall. The cooperative sharing functionality is provided by the BEACH software. For maximum flexibility and mobility each chair is provided with a wireless network and independent power supply.

In the first roomware generation (see Figure 25.5), we developed two versions. One has a docking facility (on the left side in Figure 25.5) so that people can bring their laptop computers and drop them into the swing-up desk, which is part of the armrest. The other version (on the right side in Figure 25.5) has an integrated pen-based computer built into the swing-up desk.

In the second roomware generation (Figure 25.6), we made a complete redesign resulting in the new version shown in the center of Figure 25.6 in front of the DynaWall and on the right side of Figure 25.7.

25.7.4 The InteracTable®

The *InteracTable®* (see Figure 25.6) is an interactive table that is designed for creation, display, discussion, and annotation of information objects. It is used by small groups of up to six people standing around it. People can write and draw on it with a pen and interact via finger or pen gestures with information objects. There is also a wireless keyboard for more extensive text input if needed. The InteracTable, with its horizontal setup display and people standing around it at each side, is an example of an interaction area with no predefined orientations, such as top and bottom, left and right, as found with vertical displays like monitors of desktop computers. Horizontal and round or oval displays require new forms of human-computer interaction. To this end, we developed in BEACH special gestures for shuffling and rotating individual information objects or groups of objects across the surface so that they orient themselves automatically. This accommodates easy viewing from all perspectives. Furthermore, one can create a second view of an object and shuffle this to the other side so that the opposite team member has the correct view at the same time. Now everybody can view the same object with the correct perspective in parallel and edit and annotate it.

FIGURE 25.6 Second Generation of Roomware: ConnecTables, CommChair, InteracTable, DynaWall

In the first roomware generation, a stand-up version (115 cm high—not shown) was built using a vertical bottom-up projection unit. A high-resolution image was projected to the top of the table providing a horizontal touch-sensitive display of 65 cm × 85 cm and a diameter of 107 cm (42 in.).

In the second roomware generation, we made a complete redesign resulting in the new version shown on the right side of Figure 25.6. In this version, the projection was replaced by a large touch-sensitive plasma display panel (PDP) with a display size of 65 cm × 115 cm and a diameter of 130 cm (51 in.).

25.7.5 The ConnecTable®

The ConnecTable® (see left side in Figure 25.7) is a new component that was developed as part of the second roomware generation. It is designed for individual work as well as for cooperation in small groups. The height of the display can be quickly adapted in order to accommodate different working situations: standing up or sitting in front of it on an arbitrary chair. The display can also be tilted in different angles to provide an optimal view. By moving multiple ConnecTables together, they can be arranged to form a large display area (see left side in Figure 25.6). Integrated sensors measure the distance between the ConnecTables and initiate the automatic connection of the displays once they are close enough. The cooperative BEACH software enables the resulting large display area to be used as a common workspace where several people can work concurrently and move information objects beyond the physical borders of the individual displays.

FIGURE 25.7 Three configurations of the ConnecTable (left) and the redesigned CommChair (right)

In the same way as for the InteracTable, people can create second views, shuffle them from one ConnecTable to the opposite one, rotate them there, and work on them in parallel with correct perspectives.

The mobility of the ConnecTables and the CommChairs is achieved by employing a wireless network connection and an independent power supply based on Nickel Metal Hydride (NiM) accumulators. The IT components are packaged in a translucent container. Because there are no rotating or inductive consumers (using passive cooling, RAM-disk, etc.), these roomware-components are completely noise free.

25.7.6 The Passage Mechanism

Passage describes a mechanism for establishing relations between physical objects and virtual information structures—that is, bridging the border between the real world and the digital, virtual world. So-called *Passengers* (Passage-Objects) enable people to have quick and direct access to a large amount of information and to "carry them around" from one location to another via physical representatives that are acting as physical "bookmarks" into the virtual world. It is no longer necessary to open windows, browse hierarchies of folders, worry about mounted drives, and so on. Passage is a concept for ephemeral binding of content to an object. It provides an intuitive way for the "transportation" of information between computers/roomware components—for example, between offices or to and from meeting rooms.

A Passenger does not have to be a special physical object. Any uniquely detectable physical object may become a Passenger. Since the information structures are not stored on the Passenger itself but only linked to it, people can turn any object into a Passenger: a watch, a ring, a pen, glasses, or other arbitrary objects. The only restriction Passengers have is that they can be identified by the Bridge and that they are unique. Figure 25.8 shows a key chain as an example of a Passenger placed on a dark area representing the real part of the "Bridge" device embedded in the margin of the InteracTable and the interface area in the front of the display representing the virtual part of the Bridge device.

Passengers are placed on so-called *Bridges,* making their virtual counterparts accessible. With simple gestures, the digital information can be assigned to or retrieved from the Passenger via the virtual part of the Bridge. The Bridges are integrated in the work environment to guarantee ubiquitous and intuitive access to data and information at every location in an office building (Cooperative Building). For example, a Bridge can be integrated into the tabletop of an interactive electronic table (InteracTable®) in the cafeteria or mounted in front of an interactive electronic wall (DynaWall®) in a meeting room.

We developed two methods for the detection and identification of passengers. The first method enables us to use really arbitrary objects without any preparation or tagging. Here, we use a very basic property of all physical objects—weight—as the identifier. Therefore, each Bridge contains an electronic scale for measuring the

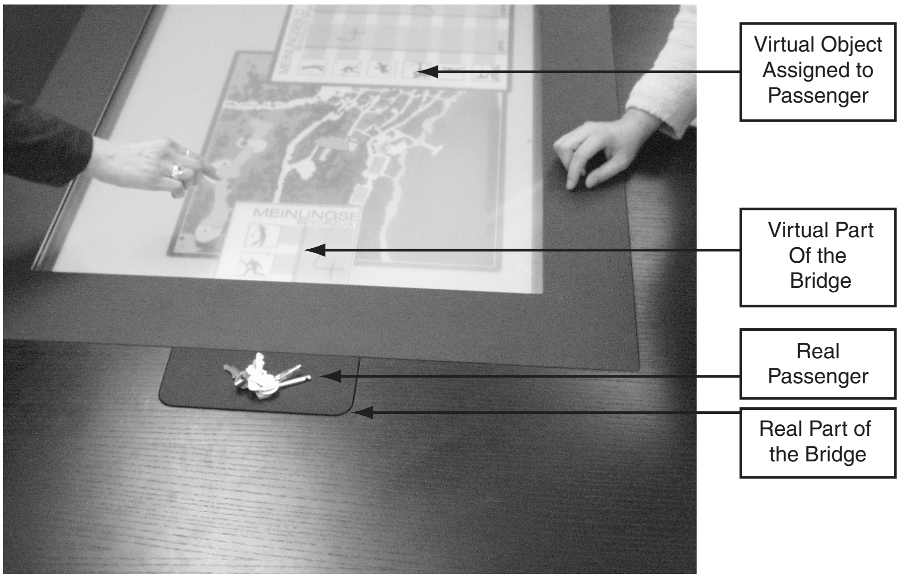

FIGURE 25.8 Passage: a key chain as a Passenger object on the Bridge of the InteracTable

weight of the Passengers (with a precision of 0.1g). This implementation is very different from other approaches in this area using electronic tags as, for example, mediaBlocks (Ullmer et al. 1998). Their approach is similar to our second method because each Bridge is also equipped with a contact-free identification device that uses radio-frequency-based transponder technology. Small electronic identification tags (RFID) that do not need batteries are attached on or embedded in physical objects so that the Passenger can be identified by a unique value. While identification via the weight of an object provides greater flexibility and is used for short-term assignments, the electronic tag method provides higher reliability and is used for long-term assignments, but it requires some preparation of the objects. For a more elaborate description and technical details of the Passage-Mechanism see Konomi et al. (1999).

25.8 Network Infrastructure

While each of these roomware components has a value of its own, the full benefit is only available via a comprehensive integration and combined use. The network infrastructure provides the connectivity between the components, while the software infrastructure provides a wide range of cooperative sharing capabilities. For extending the mobility of team members and roomware components in the whole building, it is necessary to identify them in different locations. This requires an appropriate sensing and localization infrastructure. So far, we are able to identify people in front of the three different segments of the DynaWall: the InteracTable, the ConnecTables, and the CommChairs. Extensions are planned.

In the current implementation, we use a combination of the local area network already installed in the building and an RF-based wireless network. For maximum flexibility, all mobile roomware components are connected to the wireless network. The roomware components are equipped with an antenna that comes along with a PC-Card. The computers of fixed roomware components—for example, the DynaWall—are connected via cables to the LAN. The network connection for the wireless access to the LAN is realized by a two-channel access-point that acts as a bridge between the cable-based and the RF-based Ethernet.

25.9 The Beach Software: Supporting Creativity

As already pointed out, although the design of the roomware components is generic, the development of the i-LAND environment was also application-driven. The main application is the support of team work with a focus on creativity and innovation. We support different types of creativity techniques and related generic functionality as, for example, visualization of knowledge structures. Other application areas can be organizational group memory, cooperative design activities, support for teaching and learning (electronic classroom of the future), and group entertainment environments.

In order to meet the requirements of i-LAND, we developed the BEACH software. BEACH, the *B*asic *E*nvironment for *A*ctive *C*ollaboration with *H*ypermedia, provides an architecture and a user interface adapted to the needs of roomware components, which require new forms of human-computer and team-computer interaction. Furthermore, the roomware components must be connected to allow synchronous collaboration with shared documents distributed over multiple devices. This is also important for large interaction areas like the DynaWall, which is currently realized via three separate segments because of the technical limitations of displays currently available. Other requirements are one user working with multiple devices or composite roomware, dynamic configuration of roomware, modeling also the physical environment, components to be used by different multiple users at the same time, adapting for different orientation and shape of displays, and mode-less user-interface.

BEACH has a layered architecture that is built on top of a core model. A layer with common models defines the basic interfaces for documents, user interface, tools, and interaction styles. On top of these models, a set of generic components is defined that provides the basic functionality necessary in most teamwork and meeting situations. This includes, for example, standard data types like text, graphics, and informal handwritten input (scribbles), as well as private and public workspaces for generic collaboration support. Based on the common models and the generic components modules, specific support can be added, which defines tailored functionality for distinct tasks. For more details on BEACH see Tandler (2000, 2001). BEACH is built on top of the COAST framework (Schuckmann et al. 1996) as a platform for the distribution of objects. COAST was previously developed at GMD-IPSI and was also used for the implementation of the groupware system DOLPHIN (Streitz et al. 1994).

It was a high-level design goal for the user-interface of BEACH to rely as much as possible on intuitive actions people are used to in their day-to-day physical interaction space. As a result, gestures and pen-based input are the major interaction types. Standard input devices like a mouse and a keyboard are also supported but play a minor role. A prominent and convincing example is the provision of the "shuffle" functionality where users can "throw" objects and depending on the momentum provided by the user, objects are flying faster or slower and covering a larger or shorter distance.

In contrast to "normal" mouse input, where the mouse position is always at a single, exact point, the handling of pen input is a little more demanding. Pen input normally consists of strokes touching several view objects (UI elements) on the display. This makes it impossible to use the position of the stroke as a distinct criterion. It is also important to be tolerant of inaccuracy of the input. Furthermore, it has to be decided whether a stroke should be interpreted as a command or data input. When a user has entered a stroke with a pen in the BEACH user interface, the shape of the stroke is continuously analyzed whether it is of a known form or not. The distinction as to whether the stroke is interpreted as a gesture invoking a command or as scribbled information is completely up to the controller handling pen events. It offers the possibility of context-sensitive semantic gestures.

BEACH offers a mode-less user-interface where the user does not have to select different modes before an action. It does not matter if he or she wants to provide handwritten input via a scribble or to make a "command" gesture operating on existing objects or creating new objects. This is achieved by implementing an incremental recognition of gestures: While a stroke is recorded, the current shape is continuously computed. This is then used to give feedback to the user (via different colors of the lines created) and inform him or her in this way about the operation resulting from this action.

25.10 Conclusion

We have presented the design and implementation of roomware components as central constituents of our vision of "Cooperative Buildings" for the workspaces of the future. They are based on an integrated design of real architectural and virtual information spaces going beyond the traditional desktop computer. Our approach is related to and was inspired by different developments in human-computer interaction, augmented reality, ubiquitous computing, and computer-supported cooperative work, in particular meeting support systems.

Our initial experiences are quite promising. In addition to our AMBIENTE-Lab in Darmstadt, we have had two external installations of i-LAND since May 2000 (one at the DASA in Dortmund, one at Wilkhahn in Bad Münder) that are still ongoing. Both were part of registered projects of the world exhibition EXPO 2000 but are still operated. Previous to that, we demonstrated i-LAND at different international fairs (CeBIT 1999 and 2000; Orgatec 2000). In October 2000, the roomware components of the second generation won the International Design Award of the state Baden Württemberg in Germany. More information about our future developments can be found at http://www.darmstadt.gmd.de/ambiente.

A final comment: Considering the affordances of the architectural space as a guiding metaphor for designing environments supporting the cooperation between humans and their interaction with information is a very important perspective for us. Mechanisms like "Passage" employing arbitrary real world objects as "Passengers," interaction forms like "throwing" information objects on large interactive walls, and other activities reported here seem to provide new intuitive forms of cooperation and communication. They are pointing in a similar direction as related developments emphasizing the importance of physical, tangible objects summarized in the section on related work. Nevertheless, it remains to be seen how far the use of these concepts and metaphors will actually carry. In the end, this is an empirical question that has to be answered, and we plan to address it. There is also a need for a more comprehensive approach as it is the objective of the new EU-funded proactive initiative "The Disappearing Computer" (www.disappearing-computer.net).

Notes: The term *roomware*® and the names of the roomware components *DynaWall*®, *InteracTable*®, and *CommChair*® are registered trademarks of GMD. The name *ConnecTable*® is a registered trademark of our cooperation partner Wilkhahn.

Acknowledgments

We would like to thank Jörg Geißler, Torsten Holmer, and Thorsten Prante as well as many of our students for their valuable contributions to various parts of the i-LAND project and in the AMBIENTE division of GMD-IPSI in Darmstadt. Furthermore, we appreciate the cooperation with Heinrich Iglseder, Burkhard Remmers, Frank Sonder, and Jürgen Thode from the German office furniture manufacturer Wilkhahn and Michael Englisch from their design company WIEGE in the context of the R&D consortium "Future Office Dynamics" (FOD), which sponsored part of the work presented here.

References

Baecker, R. (Ed.). (1993). *Readings in groupware and computer-supported cooperative work.* San Mateo: Morgan Kaufmann Publishers.

Bly, S.A., Harrison, S.R., and Irwin, S. (1993). Media spaces: Bringing people together in a video, audio, and computing environment. *Communications of the ACM,* 36, 1, 28–47.

Buxton, W. (1997). Living in augmented reality: Ubiquitous media and reactive environments. In K. Finn, A. Sellen, and S. Wilbur (Eds.), *Video-Mediated Communication,* 363–384. Hillsdale, NJ: Lawrence Erlbaum.

Cooperstock, J., Fels, S., Buxton, W., and Smith, K. (1997). Reactive environments: Throwing away your keyboard and mouse. *Communications of the ACM,* 40, 9, 65–73.

Fitzmaurice, G., Ishii, H., and Buxton, W. (1995). Bricks: Laying the foundations for graspable user interfaces. *Proceedings of the CHI'95 ACM Conference on Human Factors in Computing Systems,* 442–449. New York: ACM Press.

FOD (1999). "*Future Office Dynamics" Consortium.* http://www.future-office.de.

Ishii, H., and Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. *Proceedings of the CHI'97 ACM Conference on Human Factors in Computing Systems,* 234–241. New York: ACM Press.

Konomi, S., Müller-Tomfelde, C., and Streitz, N. (1999). Passage: Physical transportation of digital information in cooperative buildings. In N. Streitz, J. Siegel, V. Hartkopf, and S. Konomi (Eds.). *Proceedings of the Second International Workshop on Cooperative Buildings (CoBuild'99),* 45–54.

Mark, G., Haake, J., and Streitz, N. (1997). Hypermedia use in group work: Changing the product, process, and strategy. *Computer Supported Cooperative Work: The Journal of Collaborative Computing,* 6, 327–368.

Norman, D. (1998). *The invisible computer.* Cambridge, MA: MIT Press.

Nunamaker, J.F., Briggs, R.O., and Mittleman, D.D. (1995). Electronic meeting systems: Ten years of lessons learned. In D. Coleman and R. Khanna (Eds.), *Groupware: Technology and Applications,* 149–193. Upper Saddle River, NJ: Prentice-Hall.

Olson, J., Olson, G., Storrosten, M., and Carter, M. (1993). Groupwork close up: A comparison of the group design process with and without a simple group editor.

In T. Malone and N. Streitz (Eds.), *Special Issue on CSCW. ACM Transactions on Office Information Systems,* 11, 4, 321–348.

Pedersen, E., McCall, K., Moran, T., and Halasz, F. (1993). Tivoli: An electronic whiteboard for informal workgroup meeting. *Proceedings of InterCHI'93 ACM Conference on Human Factors in Computing Systems,* 391–399. New York: ACM Press.

Poynor, R. (1995). The hand that rocks the cradle. *I.D.—The International Design Magazine.* May-June.

Raskar, R., Welch, G., Cutts, M., Lake, A., Stesin, L., and Fuchs, H. (1998). The office of the Future: A unified approach to image-based modeling and spatially immersive displays. *Proceedings of SIGGRAPH98.* New York: ACM Press.

Rekimoto, J. (1997). Pick-and-drop: A direct manipulation technique for multiple computer environments. *Proceedings of the UIST'97 ACM Conference on User Interface Software Technology,* 31–39. New York: ACM Press.

Rekimoto, J. (1998). Multiple-computer user interfaces: A cooperative environment consisting of multiple digital devices. In N. Streitz, S. Konomi, and H. Burkhardt (Eds.), *Proceedings of the First International Workshop on Cooperative Buildings (CoBuild'98),* 33–40

Rekimoto, J., and Saitoh, M. (1999). Augmented surfaces: A spatially continuous work space for hybrid computing environments. *Proceedings of the CHI'99 ACM Conference on Human Factors in Computing Systems,* 378–385. New York: ACM Press.

Saund, E. (1999). Bringing the marks on a whiteboard to electronic life. In N. Streitz, J. Siegel, V. Hartkopf, and S. Konomi (Eds.), *Proceedings of the Second International Workshop on Cooperative Buildings (CoBuild'99),* 69–78.

Schuckmann, C., Kirchner, L., Schümmer, J., and Haake, J. (1996). Designing object-oriented synchronous groupware with COAST. *Proceedings of CSCW'96 ACM Conference on Computer-Supported Cooperative Work,* 30–38. New York: ACM Press.

Stefik, M., Foster, G., Bobrow, D., Khan, K., Lanning, S., and Suchman, L. (1987). Beyond the chalkboard: Computer support for collaboration and problem solving in meetings. *Communication of the ACM,* 30, 1, 32–47.

Streitz, N., Geißler, J., Haake, J., and Hol, J. (1994). DOLPHIN: Integrated meeting support across LiveBoards, local and desktop environments. *Proceedings of CSCW'94 ACM Conference on Computer-Supported Cooperative Work,* 345–358. New York: ACM Press.

Streitz, N., Geißler, J., and Holmer, T. (1998a). Roomware for cooperative buildings: Integrated design of architectural spaces and information spaces. In N. Streitz, S. Konomi, and H. Burkhardt (Eds.), *Proceedings of the First International Workshop on Cooperative Buildings (CoBuild'98),* 4–21.

Streitz, N., Konomi, S., and Burkhardt, H. (Eds.). (1998b). *Cooperative buildings—Integrating information, organization and architecture. Proceedings of the First International Workshop on Cooperative Buildings (COBuild'98).* LNCS 1370. Springer-Verlag, Heidelberg.

Streitz, N., Rexroth, P., and Holmer, T. (1997). Does "roomware" matter? Investigating the role of personal and public information devices and their combination in meeting room collaboration. *Proceedings of ECSCW'97 European Conference on Computer-Supported Cooperative Work,* 297–312. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Streitz, N., Rexroth, P., and Holmer, T. (1998c). Anforderungen an interaktive Kooperationslandschaften für kreatives Arbeiten und erste Realisierungen. In T. Herrmann and K. Just-Hahn (Eds.), *Groupware und organisatorische Innovation. Proceedings of D-CSCW'98,* T237—250. (In German)

Streitz, N., Geißler, J., Holmer, T., Konomi, S., Müller-Tomfelde, C., Reischl, W., Rexroth, P., Seitz, R., and Steinmetz, R. (1999a). i-LAND: An interactive landscape for creativity and innovation. *Proceedings of CHI'99 ACM Conference on Human Factors in Computing Systems,* 120–127. New York: ACM Press.

Streitz, N., Siegel, J., Hartkopf, V., and Konomi, S. (Eds.). (1999b). *Cooperative Buildings—Integrating information, organizations, and architecture. Proceedings of the Second International Workshop (CoBuild'99).* LNCS 1670. Heidelberg: Springer.

Tandler, P. (2000). Architecture of BEACH: The software infrastructure for roomware environments. Workshop presentation at *ACM Conference on Computer-Supported Cooperative Work (CSCW'2000).*

Tandler, P. (2001). Software infrastructure for ubiquitous computing environments supporting synchronous collaboration with multiple single- and multi-user devices. *Proceedings of UBICOMP 2001: Lecture Notes in Computer Science.* Heidelberg: Springer.

Ullmer, B., Ishii, H., and Glas, D. (1998). MediaBlocks: Physical containers, transports, and controls for online media. *Proceedings of SIGGRAPH'98,* 379–386. New York: ACM Press.

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

Weiser, M. (1998). The invisible interface: Increasing the power of the environment through calm technology. Opening keynote speech at the *First International Workshop on Cooperative Buildings (CoBuild'98).* Abstract of the speech available at http://www.darmstadt.gmd.de/CoBuild98/abstract/0weiser.html.

Wellner, P., Mackey, W., and Gold, R. (Eds.). (1993). Computer-augmented environments: Back to the real world. *Special Issue of Communications of the ACM,* 36, 7.

Wisneski, C., Ishii, H., Dahley, A., Gorbet, M., Brave, S., Ullmer, B., and Yarin P. (1998). Ambient displays: Turning architectural space into an interface between people and digital information. In N. Streitz, S. Konomi, and H. Burkhardt (Eds.), *Proceedings of the First International Workshop on Cooperative Buildings (CoBuild'98).* LNCS 1370. Springer-Verlag, Heidelberg. 22–32.