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*A trio of systems illustrates the challenges of designing large displays for use in ubiquitous computing environments that are, indeed, unremarkable.*

# *Building* DISAPPEARING COMPUTERS

As Weiser's seminal paper on ubiquitous computing [12] pointed out, the most ubiquitous technologies are those that form the background of the way we expect things to work. That is, the technology disappears into the fabric of the world, becoming part of what we all take for granted. Weiser notes that electric motors are an invisible technology, and that for ubiquitous computing technology to succeed, it too must become unremarkable.

But how does a computational technology become unremarkable? How can we succeed at making computers disappear into the walls and interstices of our living and working spaces?

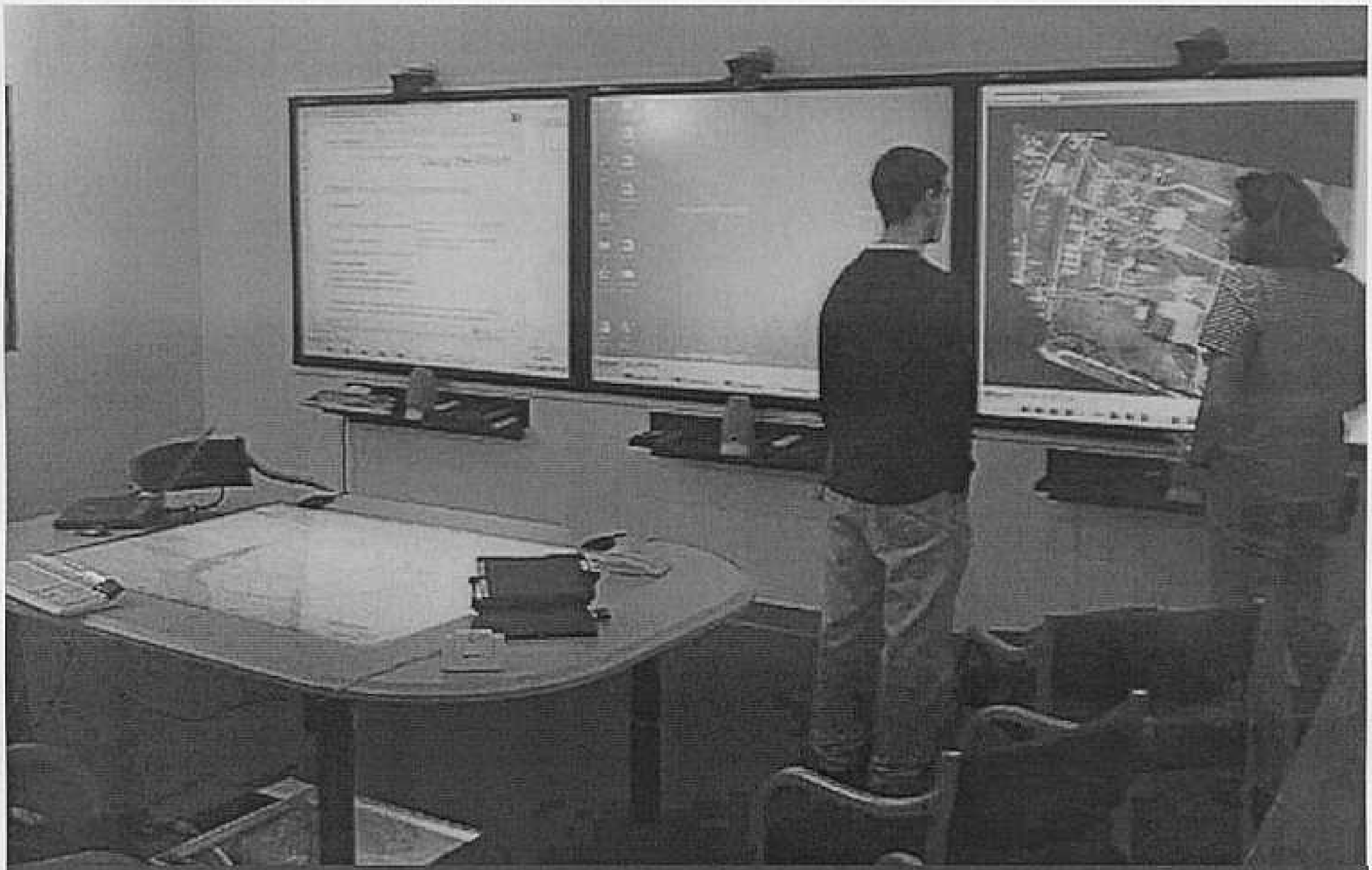

Figure 1a. A view of the Interactive Room (iRoom). It includes three commercial touch-screen displays and a bottom-projected table, along with a specialized high-resolution display (9 megapixels) using tiled projection.

Figure 1b. Second-generation Roomware at Fraunhofer IPSI: ConnecTables, CommChair, InteracTable, and DynaWall.

Here, we present three different approaches addressing the common issue of how to design and build disappearing computers. Their common focus is on integrating large display and interaction areas into the physical/architectural context, becoming part of the environment where people meet, interact with each other, share, and process information. They combine interaction in the real world with interaction in the digital world of information and communication. In this way, the "world around us" constitutes the interface to information and a medium for the cooperation of people. Each of these approaches has been developed over some time, using different implementations to find answers and solutions to the open problems and issues. In each project, the goal is to make the computer as a device "disappear" while at the same time making functionality ubiquitously available.

**Interactive Workspaces at Stanford University: iROOM.** Stanford's Interactive Workspaces project explores new possibilities for people working together in technology-rich spaces. An Interactive Workspace is a place for people to work effectively together, bringing their computational devices and networked resources into an environment where they can share and collaboratively interact with information of many types.

An Interactive Workspace combines large displays with smaller interaction devices, through an integrated suite of software that allows them to work together smoothly. This core software provides a base set of capabilities that link each device to all others in the room, using a shared event system called the EventHeap [4]. It gives users the ability to move data and applications from place to place, creating a user experience of focusing on the joint work rather than on manipulating devices, displays, and widgets. The software provides tools for sharing control through a generalized scheme of pointer redirection from any device to any other (PointRight), lightweight ways of transferring information across devices and displays (MultiBrowse), pen-based interaction that captures the benefits of high-resolution wall screens (PostBrainstorm) and other interaction software, all designed to maximize fluid interaction. Together these constitute what we call the "overface;" that is, a consistent and simple set of mechanisms that work on top of conventional devices, operating systems, and browsers to extend the user's effective reach from a device to a whole-room environment (see Figure 1).

Many interactive workspaces have been constructed, ranging from a high-tech iRoom to a simplified version using a single standard projector with wireless connection for laptops. All of them share a base infrastructure that melds the otherwise diverse set of elements into an operational whole. The architecture supports dynamically changing environments, in which components come and go, and the overall ensemble is robust in the face of individual failures.

The experimental iRoom has gone through multiple versions, each containing large touch-screens, high-resolution displays (for example, the Interactive Mural, a 9-megapixel, 2-meter wide interactive display), an interactive table (iTable), cameras for video connectivity, scanners and wireless infrastructure for experiments in connecting different devices into the iRoom system, including simple wireless tangible input devices (iStuff). From the time it was first constructed in 2001, we have been using the iRoom as an everyday workspace for our own research groups, for a number of collaborations with application development groups, for courses and student projects, and for structured experiments.

> ***How does a computational technology become unremarkable?*** How can we succeed at making computers disappear into the walls and interstices of our living and working spaces?

**Smart Environments at Fraunhofer IPSI: AMBIENTE.** Research in Fraunhofer IPSI's AMBIENTE Division is based on the notion of "Cooperative Buildings" [6], grounding the design of work and communication environments by analyzing the affordances of physical/architectural spaces and responding to the demands of new work practices. These environments combine the informatization of real-world objects that link real and virtual worlds to create hybrid worlds populated with smart artifacts such as the Roomware components including interactive walls (DynaWall), tables (InteracTable), chairs (CommChair), desks (ConnecTable), and ambient displays (Hello.Wall). Such tools vary from very small to very large, coming in new places, positions, and orientations in the workplace, giving rise to new ways of interacting between people. Collections of Roomware devices have been used since 1997 for designing comprehensive meeting room environments [7] and later for extending the scope to semi-public spaces (such as lounges and hallways [8]), as part of Cooperative Buildings.

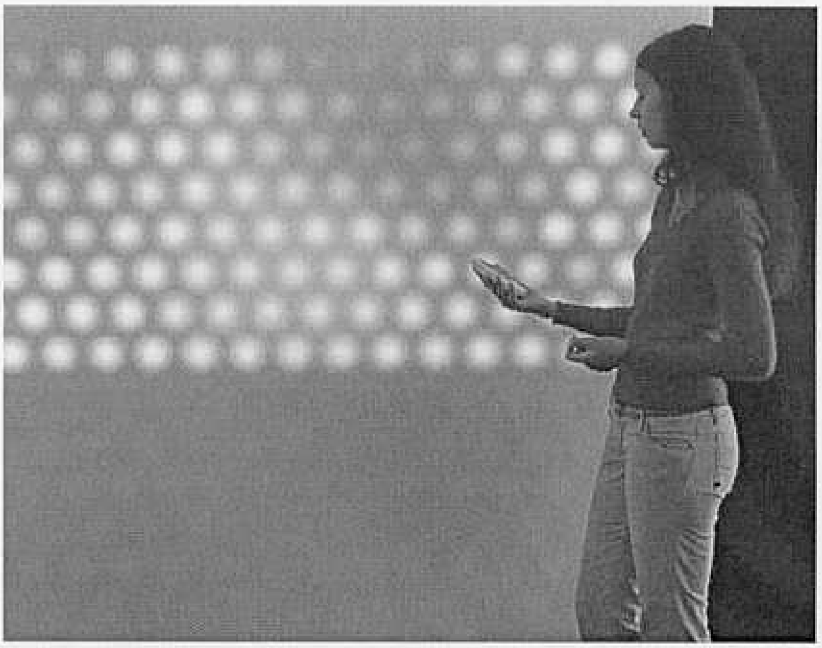

Figure 2. Using the mobile ViewPort device in front of the ambient Hello.Wall display.

The DynaWall is a wall-size (4.5m x 1.1m) touch-sensitive interactive display tightly integrated with the surrounding wall. As a consequence of its size, it requires new forms of interaction, especially when going beyond standard desktop-like interaction. The Beach software [9] provides a modeless gesture-based interaction and facilitates to move information objects on the wall from one side to the other (a long distance) by throwing and shuffling visual objects with different accelerations and sounds.

The DynaWall is a vertical display, while the InteracTable is a horizontal display with its own set of interaction issues. The software allows users to create multiple views of an object, and rotate these objects so that people can work on the same content with their individual perspective in parallel. Synchronizing group work between different users of Roomware devices is also supported, such as allowing a user to create and edit objects on the DynaWall remotely while sitting relaxed in a CommChair providing a personal and a shared public work space (see Figure 1b).

The goal of the Ambient Agoras project is to transform everyday places into social marketplaces ("agoras" in Greek) of ideas and information where people can meet and interact. Providing situated services, place-relevant information, and feeling of the place facilitates enabling people to communicate for help, guidance, work, or fun [3, 8]. One application communicates information about the presence of people in the office building, their overall mood and their individual accessibility in a lightweight, ambient fashion. The Hello.Wall is a large display (2.0m wide x 1.80m high) showing dynamic light patterns made by light-emitting cells organized in an array structure. It also contains sensing technology to detect people passing by within a given distance of the display. Depending on its particular use, the Hello.Wall provides awareness and notifications to people by different, dynamic light patterns mapped on different types of information. In addition, the ViewPort—a wireless PDA for personal information—can also be "borrowed" by the Hello.Wall to present additional information details that go beyond the expressive power of the light patterns. Remote teams in two distant sites can be made aware of each other, and notified when chances for spontaneous informal encounters arise (see Figure 2).

**BlueBoards at IBM Almaden Research Center.** The IBM BlueBoard is a large, interactive display surface based on a plasma display with a touch-screen and a badge reader for personal identification, allowing people to quickly log in by simply swiping their ID badge. It has an integrated PC running thin-client software to support rapid diagram sketching and content-sharing between people using the board. In effect, the BlueBoard is a large publicly accessible system that allows users to quickly access their networked content (such as email, calendars, and presentations), view their content, annotate, and share.

Like the other systems discussed here, BlueBoard is intended to be a part of the current workplace: a common tool embedded within a wall, freely standing in a conference room, or easily movable from place to place as needs arise and physical space changes. We have consciously avoided overly complex mechanisms such as group management, workflow systems, or floor controls. An important goal is that the BlueBoard be usable with the materials at hand, and with only a tiny amount of training. To simplify things, the current BlueBoard design allows only physically co-present people to share content, and sharing is done by sending shared materials via email so that BlueBoard use becomes a straightforward extension of current working practices. Rather than invent all new mechanisms, BlueBoard was designed to integrate smoothly into current work styles, extending current practices into new locations in the workplace.

The BlueBoard is intended for both very fast personal use (walk up, check your calendar, walk away—all within five seconds), and for small group collaborative use (a small number of people stand around the BlueBoard to sketch ideas, pull up information from their personal space, compare notes, share content, or create something new [11]).

Like the iRoom and Roomware, IBM's BlueBoard design evolved by experiences during deployment. Initially targeted for short-term, ephemeral, and spontaneous hallway use, we quickly realized the original design was too invasive in the business hallway space—people just would not use a device that did not fully melt into the background. In effect, the first iteration of BlueBoard did not achieve "disappearance" because of its novelty, size, and brightness in the hallway.

We then moved BlueBoard to a more conventional group meeting space where its appearance was fairly unremarkable and its function more suited to sit-down style meetings (see Figure 3). As a consequence of being used in longer meetings, new capabilities were added in response to the newly emerging requirements of BlueBoard use (for example, video conference support and the ability to do iRoom-like multibrowsing [4]).

## Common Issues from Common Experiences

In all three sites, a common goal has been to push computing technology for group work into the background. That is, to make the use of all the underlying technology into something simple and straightforward enough to become an expected part of the architecture and at the same time to provide functionality in the sense of a Cooperative Building.

> Our emerging design philosophy is one of designing the infrastructure for integration and evolution. ***As we discovered, stable systems do not exist when we are dealing with rapidly evolving technologies.***

While designing and deploying tools to accomplish this kind of disappearance in a ubiquitous environment, we have identified some common design guidelines.

*Heterogeneity.* A number of different devices will be used in the workspace, chosen for their efficacy in accomplishing specific tasks. In addition to desktop workstations, these include laptops and PDAs with wireless connections used in conjunction with shared displays integrated into furniture, as well as physical and tangible technologies specially designed for ubiquitous settings. All of these must interoperate in spite of heterogeneity in software, including legacy applications. It is infeasible in most cases to write new applications or versions just to take advantage of interactive workspace facilities. From a user perspective, interfaces must be customized to work smoothly on different-sized displays, with different input/output modalities. All three systems have different means for bringing outside devices into use as part of the whole.

*Dynamism.* Interactive work environments such as those described here are dynamic on both short and

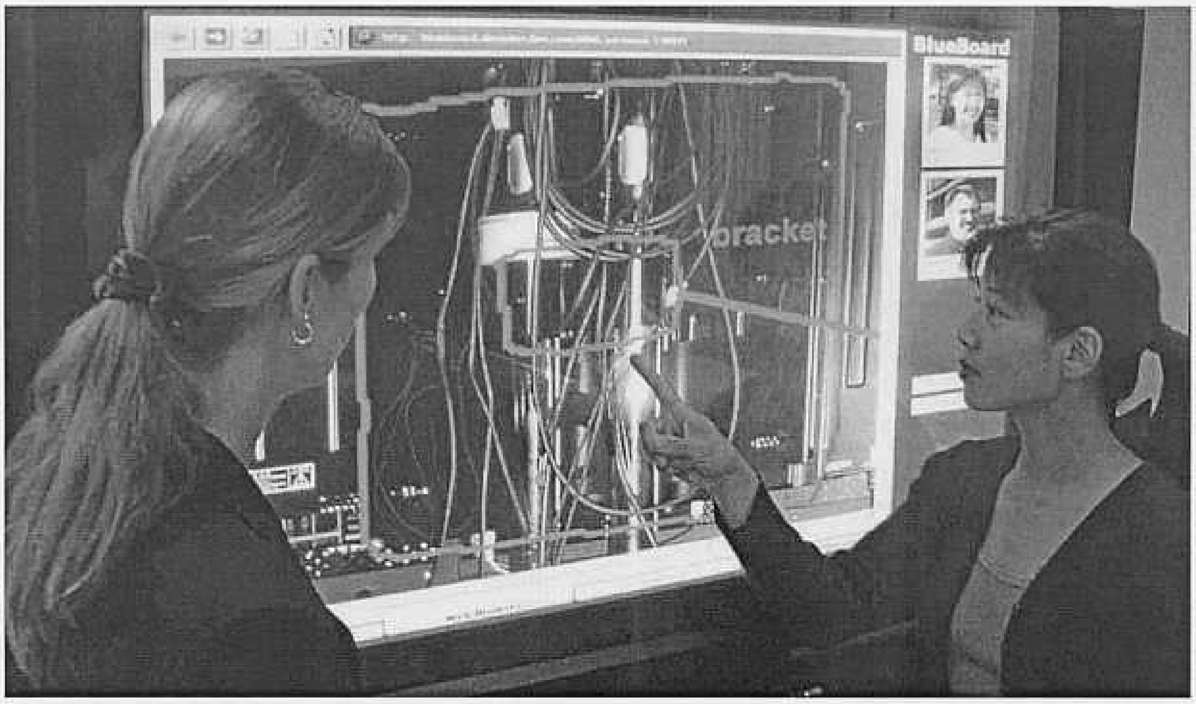


Figure 3. The IBM BlueBoard in group use.

long time scales. Over short time spans individual devices are turned on and off, wireless devices enter and exit the space, and pieces of equipment may break down for periods of hours or days. On longer time scales, the workspaces will incrementally evolve as new devices are introduced. The dynamic nature of workspaces means a software framework must handle applications and devices joining and leaving while minimizing the impact on other entities in the space.

*Robustness.* For interactive workspaces to become widely deployed they need system stability in the face of change and transient failures. They must "just work" without requiring full-time administration. Users will treat the devices in interactive workspaces as appliances that should not fail in unexplainable ways. Thus, failure must be anticipated as a common case, rather than an exception [5]. All of this means the software framework must ensure that failures in individual applications and devices are noncatastrophic, and must provide for quick recovery, either automatically or by providing a simple set of recovery steps for the users.

*Interaction techniques.* Although each space is superficially different (BlueBoard's single vertical display, iRoom's multiple wall and table displays, Roomware's multiple walls, tables, and chairs), in all cases we had to devise methods intrinsic to the style of the interaction surface. A long, large wall space needs an interaction technique suited to its size and location (such as DynaWall's toss and shuffling technique [7, 9], or iRoom's zooming techniques for spatially manipulating images smoothly on large displays [1]).

Groups of people working together need to identify themselves to the environment in a fast, simple way (for example, BlueBoard's pcon badge-in method [10]). At the same time, such large-scale embedded environments must have very easy-to-use interaction methods; for example, gesture-based interaction. These differ from conventional interfaces designed for individual work, which can use keyboard input with complex modes, states, and shortcut commands. Group-oriented work in a ubiquitous environment calls for an interface style that is less cognitively demanding and supports joint activity by multiple users. An important aspect of large ubiquitous systems is they are not owned by any one person, but are a common resource. As a consequence, users don't read documentation on how to use the system, but rely chiefly on experiences of daily use to learn the system. Overt interface techniques make this kind of social learning possible [10].

One outgrowth of the need to make these systems simple to use has been the development of *ambient* information displays that show information about the activities of the working groups into which our systems are embedded. Both Hello.Wall and BlueBoard have modes in which information is pushed subtly into the working space as with the slowly shifting glowing dot light patterns on the Hello.Wall [8], or with more overt notices about group status as in BlueBoard's IMHere application [2].

Our designs focus not on solving the problem as we see it today, ***but on facilitating evolutionary progress into the future.***

## Conclusion

As we look at our three very different systems, it has become clear that making large, in-building ubiquitous computing systems requires extraordinary attention to the details of interaction by a community of users, the design of the overall system for simplicity of use, and the placement of the devices within the physical space.

Our emerging design philosophy is one of designing the infrastructure for integration and evolution. As we discovered, stable systems do not exist when we are dealing with rapidly evolving technologies. As a corollary, we cannot expect people to discard their existing systems and workspaces in favor of newer technology: a clearly new capability must be provided by the ubiquitous system, and some degree of backward compatibility must be retained, while the ability to smoothly and incrementally integrate and migrate to new technology must be provided. Today's exotic new hardware and latest-version software are tomorrow's legacy components.

Consequently, our designs focus not on solving the problem as we see it today, but on facilitating evolutionary progress into the future. Rather than investigating systems, application suites, and their use just in our specific spaces, each project has resulted in investigating software and design techniques that can be used in differently configured interactive workspaces. Our common goal has been to create frameworks that apply to any interactive workspace, and to then put these tools in places where they can be used easily, simply, and effectively. Success for us is the disappearance and the quiet acceptance of the tools we build as essential parts of the workplace. ◼

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