Designing Smart Artifacts for Smart Environments

Smart artifacts promise to enhance the relationships among participants in distributed working groups, maintaining personal mobility while offering opportunities for the collaboration, informal communication, and social awareness that contribute to the synergy and cohesiveness inherent in collocated teams.

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An integral part of our environment, computers contribute to the social context that determines our day-to-day activities while at the office, on the road, at home, or on vacation. The widespread availability of devices such as desktop and laptop computers has fueled our increasing dependency on a wide range of computing services. The technological advances that underlie the laptop, PDA, or cell phone also provide the foundation for nontraditional computer-based devices such as interactive walls, tables, and chairs—examples of *roomware* components that provide new functionality when combined with innovative software.[1]

Two complementary trends have resulted in the creation of *smart environments* that integrate information, communication, and sensing technologies into everyday objects.[2] First, continual miniaturization has resulted in computers and related technological devices that are small enough to be nearly invisible. Although they are not visible, these devices still permeate many artifacts in our environment. Second, researchers have augmented the standard functionality of everyday objects to create *smart artifacts* constituting an environment that supports a new quality of interaction and behavior.

In our work, we distinguish between two types of smart artifacts: *system-oriented, importunate smartness* and *people-oriented, empowering smartness*.

System-oriented, importunate smartness creates an environment in which individual smart artifacts or the environment as a whole can take certain self-directed actions based on previously collected information. For example, a space can be smart by having and exploiting knowledge about the persons and artifacts currently situated within its borders, for example, how long they have occupied the space and what actions they have performed while in it.

In this version of smartness, the space would be active, in many cases even proactive. It would make decisions about what to do next and actually execute those actions without a human in the loop. In a smart home, for example, the control system automatically performs functions such as adjusting the heating system and opening or closing the windows and blinds.

In some cases, however, these actions could be unwelcome or ill-timed. Consider a smart refrigerator that analyzes the occupants' consumption patterns and autonomously orders replacements for depleted menu items. Although we might appreciate suggestions for recipes we can make with the food that is currently available, we would probably resent a smart refrigerator that ordered food automatically that we could not consume because of circumstances beyond the refrigerator's knowledge such as an unanticipated absence or illness.

In contrast, people-oriented, empowering smartness places the empowering function in the foreground so that "smart spaces make people smarter." This approach empowers users to make decisions and take mature and responsible actions.

Developing future applications of ubiquitous and ambient computing in smart workspaces required a wide range of expertise and a highly interdisciplinary approach.

In this case, the system also collects and aggregates data about what goes on in the space, but it provides and communicates this information intuitively so that ordinary people can comprehend and determine the system's subsequent actions. This type of smart space might make suggestions based on the information collected, but users remain in the loop and can always decide what to do next.

This type of system supports its occupants' smart, intelligent behavior. In an office scenario, for example, the smart space could recommend that current occupants consult with others who worked on the same content while occupying the same space earlier or it could direct them to look at related documents created earlier in the same space.

The system-oriented and people-oriented approaches represent the end points of a line along which we can position weighted combinations of both types of smartness depending on the application domain. Although in some cases it might be more efficient if the system does not ask for a user's feedback and confirmation at every step in an action chain, the overall design rationale should aim to keep the user in the loop and in control whenever possible.

FROM INFORMATION TO EXPERIENCE

Much work on smart things and environments focuses on intelligently processing the data and information that supports factory and home control and maintenance tasks or productivity-oriented office tasks. We considered another promising dimension, however: designing *experiences* via smart spaces.

We sought to design smart artifacts that users can interact with simply and intuitively in the overall environment. This includes extending awareness about the physical and social environment by providing observation data and parameters that—in many cases—are invisible to unaugmented human senses. Revealing this information thus enables new experiences.

This process of capturing and communicating invisible parameters is applicable to both known existing action contexts and to newly created situations and settings. Known examples include pollution or computer network traffic data that usually escapes detection by the human senses.[3] Presenting this data can provide a new experience that gives people a deeper sense of what occurs around them. Depending on the particular application, this capability could raise public awareness and potentially trigger changes in people's behavior.

Our work in creating augmented social architectural spaces in office settings culminated in the Ambient Agoras environment (www.ambient-agoras.org).[4] We are now applying this knowledge to other domains, including interactive hybrid games, home entertainment, and extended home environments.

We focus here on computer-based support for activities beyond direct productivity, in particular informal communication and social interaction between local and remote teams in an organization that are working at different but connected sites.[5,6] Because these activities are important to an organization's overall progress and success, they merit more technology-based support.

Ambient Agoras

Within this overall context, we used the Ambient Agoras environment as a test bed for developing future applications of ubiquitous and ambient computing in smart workspaces. This required a wide range of expertise and a highly interdisciplinary approach involving not only computer scientists and electrical engineers but also psychologists, architects, and designers.

Fraunhofer IPSI in Darmstadt, Germany, provided the scientific, technical, and administrative project coordination. Fraunhofer's Ambiente Research Division also employed product designers and architects to develop some of the artifacts.

Electricité de France, the French electrical power utility, served as the consortium's user organization. As part of its R&D division, the Laboratory of Design for Cognition in Paris provided the test bed for the evaluation studies and contributed to the observation and participatory design methods.

Wilkhahn, a German office furniture manufacturer, contributed to the design and development of some artifacts, leveraging its experience in designing the second generation of Roomware components developed in cooperation with Fraunhofer IPSI in the Future Office Dynamics consortium.[7]

Social marketplace of ideas and information

We chose as the guiding metaphor for our work the Greek *agora*, a marketplace. In line with this, we investigated how to turn everyday places into social marketplaces of ideas and information where people could meet and interact.

In our particular context, we addressed the office environment as an integrated organization located in a physical environment and having particular information needs, both at the organization's collective level and at the worker's personal level.

Overall, we sought to augment the architectural envelope to create a social architectural space that supports collaboration, informal communication, and social awareness. We achieved this by providing situated services and place-relevant information that communicate the feeling of a place to users. Further, augmented physical artifacts help promote individual and team interactions in the physical environment.

Specifically, we used a scenario-based approach, starting with a large number of so called *bits of life*—short descriptions of functionalities, situations, events, and so on—that we aggregated into scenarios and presented to focus groups using visual aids such as video mock-ups. This, in combination with extensive conceptual work based on different architectural theories,[8] served as the basis for developing a wide range of smart artifacts and their corresponding software that, together, provided users with smart services.

Design, development, and evaluation followed an iterative and rapid-prototyping approach. For the Ambient Agoras environment, we coupled several interaction design objectives, including the disappearance and ubiquity of computing devices; sensing technologies such as active and passive RFID; smart artifacts such as walls, tables, and mobile devices; and ambient displays. We then investigated the functionality of two or more artifacts working together. In particular, we addressed the

- support of informal communication in organizations, both locally and between remote sites;
- role and potential of ambient displays in future work environments; and
- combination of more or less static artifacts integrated in the architectural environment with mobile devices carried by people.

Mobility and informal communication

Several trends are changing how large organizations work. For example, organizations increasingly organize work around teams that change dynamically in response to the temporary nature of projects. People working in these organizations also experience a large degree of personal mobility in two dimensions:

- *local mobility* within the office building as a result of new office concepts such as the loss of personal office space because of shared desk policies and wide-open office landscapes with movable walls and furniture that can be adapted on the fly to changing requirements and new project team constellations; and
- *global mobility* achieved by using mobile technologies while traveling or working at different sites at the municipal, regional, national, or international level.

Informal awareness about ongoing activities in the local work environment and a sense of community both play vital roles in the workplace.

Although increased mobility offers several benefits, it also has implications that demand new responses, especially at the global mobility level.

At the local level, the usually recognized channels of communication between people working together include face-to-face conversations, formal meetings, phone conversations, e-mail messages, and document sharing. In addition, informal communication includes interactions such as chance encounters at the copying machine, hallway chats, and conversations while relaxing in the lounge. These interactions help participants stay on top of things, anticipate future developments in the organization, and exchange gossip and rumors. Like explicit verbal communication, implicit communication occurs in terms of a mutual awareness through which people can determine who's who and assess their coworkers' overall mood and morale.

Design recommendations for the workplace frequently conclude that both informal awareness about ongoing activities in the local work environment and a sense of community play vital roles in the workplace.[9] Teams that share the same physical environment generally benefit from increased informal awareness because the team members have higher mobility within the shared workspace.

When looking at global mobility, the situation changes fundamentally. The increased mobility of team members usually leads to poor communication and lack of group cohesion, which negatively affects the teams' performance. This holds true for individual global mobility caused by intensive traveling and for group global mobility in the case of distributed teams that have subgroups working at different sites.

One empirical study that addressed this topic confirmed the trend toward the formation of virtual teams, but noted that such teams reduced interpersonal relations to a minimum.[10] Further, this study showed that it is exactly these relationships between team members that have the strongest effect on performance and work satisfaction. The poor communication and lack of group cohesion often expe-

The Disappearing Computer

The European Commission funded the proactive The Disappearing Computer research initiative. Launched by the Future and Emerging Technology section of the Information Society Technology program, The Disappearing Computer initiative seeks "to explore how everyday life can be supported and enhanced through the use of collections of interacting smart artifacts. Together, these artifacts will form new people-friendly environments in which the 'computer-as-we-know-it' has no role."

The initiative has three main objectives:

- developing new tools and methods for embedding computation in everyday objects to create smart artifacts;
- investigating how new functionality and new uses can emerge from collections of interacting artifacts; and
- ensuring that people's experience of these environments is both coherent and engaging in space and time.

These objectives require research in ambient intelligence, pervasive and ubiquitous computing, and new forms of human-computer interaction. Researchers have undertaken a cluster of 17 related projects under the umbrella theme of The Disappearing Computer initiative to pursue these three objectives. The Ambient Agoras project is one of these projects.

For more information about The Disappearing Computer initiative, visit www.disappearing-computer.net or contact Norbert Streitz, chair of the DC-Net Steering Group.

rienced in virtual and distributed teams has considerable negative effects on team performance.[11]

Building on this work, we developed the constituents for a smart environment in a corporate setting that augments existing local and distributed architectural spaces, transforming them into spaces that make people "smarter" by supporting social awareness and informal communication.

POPULATING AMBIENT AGORAS

Each of the artifacts and software components we developed to populate the Ambient Agoras smart spaces, including InfoRiver, InforMall, and the SIAM-system, meets different aspects of our overall design goals.[12] We focus here on the Hello.Wall, ViewPort, and Personal Aura.

Calm technology

While working on the ideas that the Ambient Agoras embody, we set another complementary goal for implementing the technology. We felt that the implementation should correspond to and be compatible with the nature of informal communication, social awareness, and team cohesion. Our conceptual analysis combined with information gathered from focus groups showed that traditional approaches to communicating using desktop technology did not achieve this goal and would not meet expectations.

Therefore, we took a different route based on the notion of ambient displays and lightweight support with mobile devices. An observation by Mark Weiser helped inspire our decision to move the computer to the background and develop a calm technology: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."[13] The "The Disappearing Computer" sidebar describes Weiser's influence on proactive research exploring how smart artifacts can support and enhance everyday life in a people-friendly environment in which there is no role for the "computer as we know it."

Ambient displays

We decided that a calm, ambient technology best supports the informal social encounters and communication processes within a corporate building. The *ambient displays* that exemplify this approach go beyond the traditional notions of the typical displays found on PCs, notebooks, PDAs, and even many interactive walls or tables.

Some ambient displays employ nature-like metaphors to present information without constantly demanding the user's full attention. They usually achieve this implicitly by making the displays available in the periphery of attention.

Designers envision that ambient displays will spring up all around us, moving information off conventional screens and into the physical environment. They will present information via changes in light, sound, object movement, smell, and so on. Hiroshi Ishii and his colleagues at the MIT Media Lab developed several early examples of this technology.[3,14] Given that awareness of people's activities can strengthen social affiliations, ambient displays can be used to trigger the attention of team members subtly and peripherally by communicating a location's atmosphere, thus providing a sense of place.

Ambient displays provide only one aspect of the implementation, however. Another aspect is sensing people and collecting the parameters relevant to achieving the goal of providing location- and situation-based services.

Hello.Wall

We developed the Hello.Wall, our version of an ambient display, for the Ambient Agoras environment. This 1.8-meter-wide by 2-meter-high compound artifact has integrated light cells and sensing technology. As Figure 1 shows, this display facilitates communication via dynamically changing light patterns. The current version uses 124 light-emitting cells organized in an eight-row array structure.

A standard computer hidden in the background uses a special driver interface to control the Hello.Wall artifact. To adjust the LED clusters' brightness, we developed a new control unit that uses pulse-width modulation. The system's general design captures a range of parameters as input and maps them to a wide range of output patterns.

The Hello.Wall provides awareness and notifications to people passing by or watching it. Different light patterns correspond to different types of information. Using abstract patterns allows distinguishing between public and private or personal information. Although everyone knows the meaning of public patterns and can therefore interpret them easily, only the initiated can access the meaning of personal patterns. This makes it possible to communicate personal messages and information in a public space without worry that others will catch their meaning.

In the Ambient Agoras environment, the Hello.Wall functions as an ambient display that transmits organization-oriented information publicly and information addressed to individuals privately. We can think of it as an organism that radiates the breath of an organization's social body, making it perceivable to the organization's members on the inside as well as others on the outside.

The Hello.Wall does more than communicate information and atmosphere, however—its appearance also has an effect on the atmosphere of a place and thus influences the mood of the social body around it. While the artifact serves a dedicated informative role to initiated members of the organization, visitors might consider it as simply an atmospheric decorative element and enjoy its aesthetic quality.

As an integral part of the physical environment, the Hello.Wall constitutes a seeding element of a social architectural space that provides awareness to the members of an organization. In this way, the Hello.Wall is a piece of unobtrusive, calm technology that exploits people's ability to perceive information via codes. It can stay in the background, at the periphery of attention, while those around it concern themselves with another activity, such as a face-to-face conversation. The Hello.Wall's unique blend of unobtrusive, calm technology and its continual display of high-quality aesthetic patterns make it *informative art*.[15]

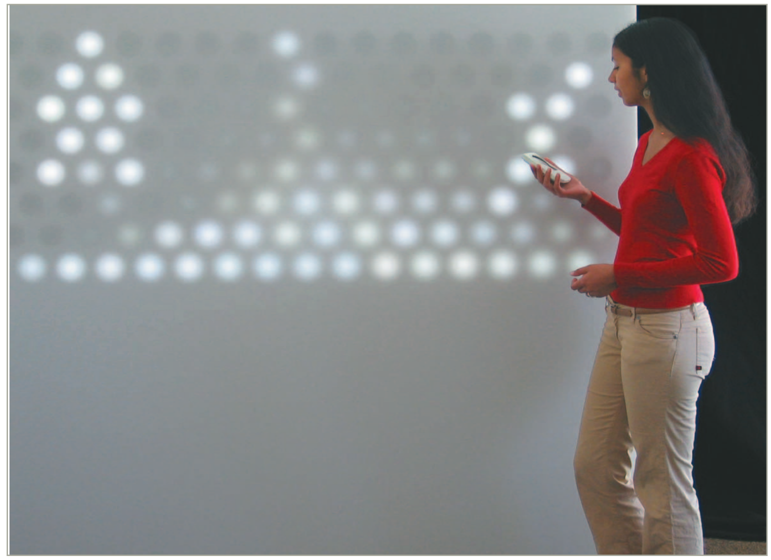

Figure 1. Hello.Wall. The ambient display combines unobtrusive, calm technology and a continual display of high-quality aesthetic patterns to convey the idea of turning everyday spaces into* agoras*—social marketplaces where people can meet and interact.

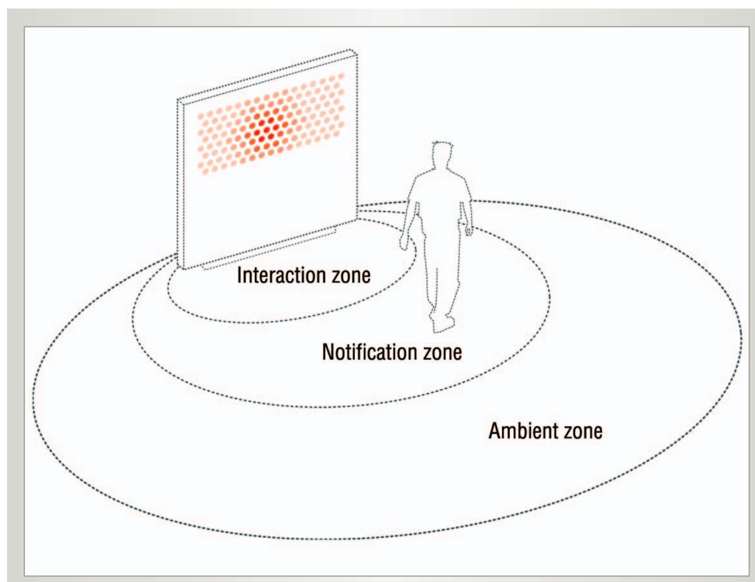

Figure 2. Communication zones. Depending on the distance from the display, the Hello.Wall has three communication zones: ambient, notification, and interaction.

Sensing and different zones of interaction

Beyond developing a new ambient display, we also sought to make the type of information and how it is communicated context-dependent. The artifact should provide services that are location- or situation-based depending on the proximity of people passing by. As Figure 2 shows, depending on the distance from the display, the Hello.Wall has three different communication zones: ambient, notification, and interaction.

To cover different ranges, we used integrated sensors that can be adapted according to the surrounding spatial conditions. Using these sensors introduces a *distance-dependent semantic*, which implies that the distance of an individual from the

Figure 3. ViewPort. (a) The implemented prototype and (b) a design prototype showing the next version's new form factor.

smart artifact defines the kind of information shown and the interaction offered.

People passing through the ambient zone contribute to and experience the ambient patterns continuously displayed on the Hello.Wall. These patterns concern, for example, general presence information. People in the notification zone are identified as individuals and agree to have the Hello.Wall-enriched environment react to their personal presence. This can result in personal notification patterns being displayed on the Hello.Wall. People in the interaction zone can get directly involved with the Hello.Wall environment. The artifact reflects this by showing special interaction patterns.

ViewPort

We designed a complementary mechanism for the Hello.Wall that can "borrow" the displays of other artifacts to communicate additional information that complements the Hello.Wall's display. As Figure 3 shows, each of these mobile ViewPorts consists of a WLAN-equipped PDA-like handheld device based on commercially available components that are mapped to a new form factor. Furthermore, we integrated RFID readers and transponders so that a ViewPort can sense other artifacts and be sensed itself.

The Hello.Wall can borrow the ViewPort's display to privately show more explicit and personal information that can be viewed only on a personal or temporarily personalized device. Depending on access rights and current context, people can use ViewPorts to learn more about the Hello.Wall, to decode visual codes on the wall, or to access a message announced by a code.

Personal Aura

People adopt different social roles in daily life, such as mother, client, or customer. In some situations, communication reveals a lot about a person, while in others it reveals very little.

In a corporate organization, employees have different professional roles that might change even during the course of a single workday. An employee can be the project manager on one team and later participate in another meeting as a regular task force member.

Based on these considerations, we wanted to provide a similar mechanism for sensor-based environments. We sought to design an easy and intuitive interface that would let users control their appearance in a smart environment. They could decide whether to be visible to a tracking system and, if so, they could control the social role in which they appeared. This mechanism contributes to the increasing discussion of privacy issues that the implementation of smart environments has generated.[16]

Figure 4 shows the Personal Aura, our first instantiation of this concept. The artifact consists of two matching parts: the reader module and the

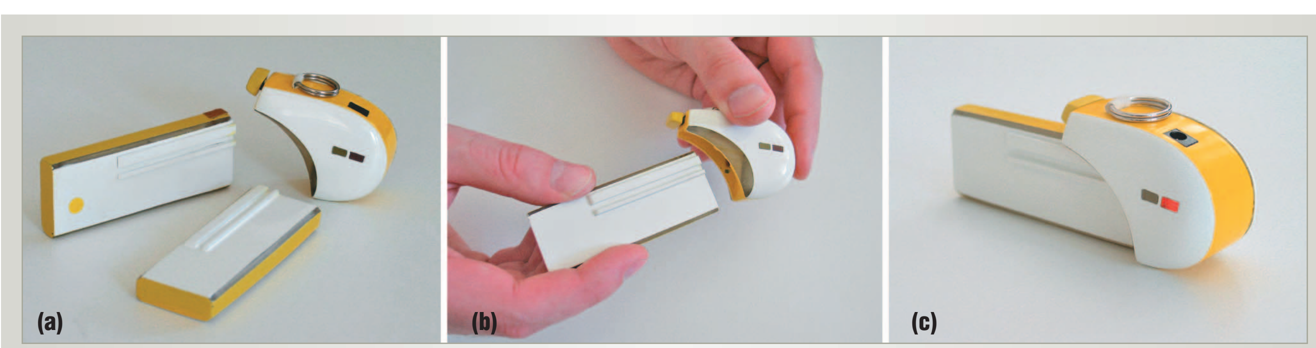

Figure 4. Personal Aura. (a) The reader module and two ID sticks, (b) connecting reader module and ID stick, and (c) an active Personal Aura.

ID stick, which contains a unique identity and optional personal information. Each person has multiple ID sticks, with each stick symbolizing a different role. If people want to signal their availability in the connecting remote team application, for example, they can do so by connecting a specific ID stick to the reader module.

CONNECTING REMOTE TEAMS

Aside from opportunistic chance encounters in the hallway, gathering in a lounge area offers people the highest accessibility to informal communication. Although a person's mood and availability for participating in a chat can be detected easily in a face-to-face situation, identifying similar information in a remote setting is difficult. People must be called or e-mailed to determine their receptiveness to an encounter. When they use standard videoconferencing systems, people usually must plan the encounter and prepare the setup in advance.

To evaluate how the Hello.Wall and its supporting artifacts could facilitate communication between two remote teams, we ran a living-lab evaluation in the fall of 2003. This scenario addressed the issue of extending awareness information and facilitating informal communication from within a corporate building to distributed teams working at remote sites.

We built and installed Hello.Wall ambient displays and the corresponding sensing infrastructures in two lounge spaces, one at EDF-LDC in Paris and the other at Fraunhofer IPSI in Darmstadt. Figure 5 shows the Hello.Wall in one of the lounge areas.

We used different media to allow the continuous exchange of information about the availability of people for chance encounters and to provide a starting point for initiating spontaneous video-based communication between the two remote sites.

We mapped the zone model to the floor plans of the lounges at each site. While people in the ambient zone only contributed to the ambient presence patterns, people entering the notification zone were identified via their Personal Aura, and their personal sign was displayed at the Hello.Wall at the opposite remote lounge space. Thus, the Hello.Wall continuously presented a combination of patterns communicating what was going on at the remote site. People could perceive this information in an ambient way without having to explicitly focus their attention on it.

When they became aware of the presence of particular people and had the feeling that it was a good time to engage in a spontaneous encounter, people needed a way to communicate their interest in an intuitive way. The request was triggered by pushing a button, which resulted in a specific pattern that overrode all other patterns on the Hello.Wall at the remote site. The remote site could reject this request or accept the invitation, and the informal video-based communication could proceed.

We used dynamic light patterns to communicate different types of information: the presence and number of people at the opposite site, their general mood, the presence and availability of specific team members, and their interest in communicating with the remote team.

We designed a specific pattern language that distinguishes between the

- ambient patterns representing general information like mood and presence;
- notification patterns handling individual or personalized messages; and
- interaction patterns handling direct communication requests, such as a request for engaging in a spontaneous video communication with a remote team member.

To give them an aesthetically pleasing and nonmonotonic appearance, we purposely designed the patterns to appear abstract. The Hello.Wall continuously displays these dynamic patterns as they interweave with each other. To reduce complexity and facilitate peripheral perception, as Figure 6 shows, the wall displays the presence and mood patterns at only three levels—low, medium, and high.

In addition, the Hello.Wall can apply overlays to these patterns. Static personal signs display when a specific team member appears in the lounge area. Figure 7 shows that each person has a specific sign, controlled by the Personal Aura. As a dedicated example of privacy-enhancing technology, the Personal Aura provides users with control over RFID-based identification in smart environments.[6]

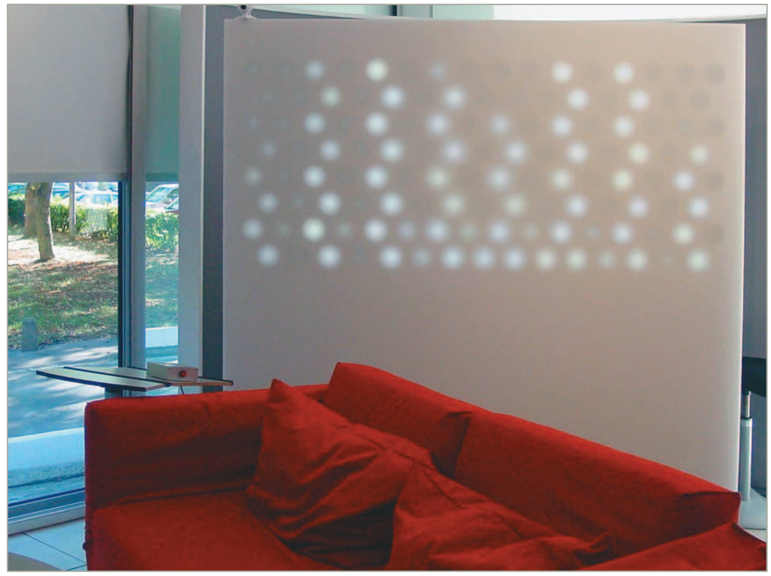

Figure 5. Hello.Wall in lounge area. The experimental setting consisted of two lounge areas, each enhanced with a Hello.Wall: one at EDF-LDC in Paris and the other at Fraunhofer IPSI in Darmstadt, Germany.

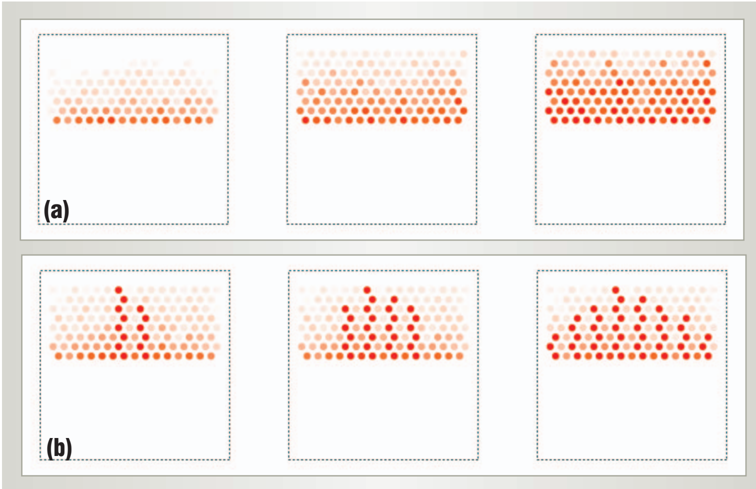

Figure 6. Hello.Wall patterns. The patterns express (a) three different levels of mood and (b) three different levels of presence—low, medium, and high.

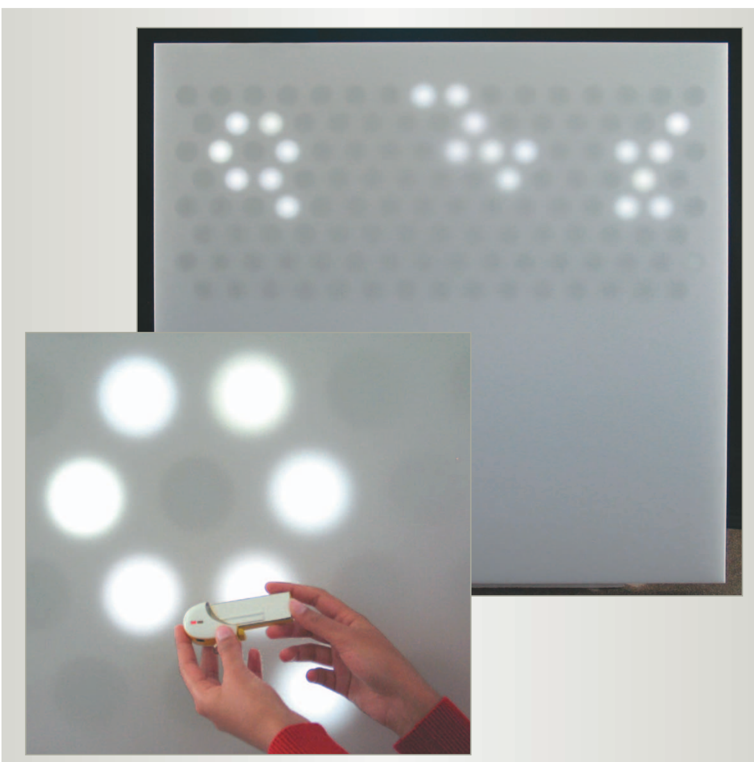

Figure 7. Static personal signs. The Personal Aura privacy-enhancing technology controls different personal signs, each indicating a specific person's presence and role.

Using questionnaires to provide feedback revealed that our approach was effective in facilitating workplace awareness and group communication. Our evaluation demonstrated that participants could learn how to identify and interpret the Hello.Wall patterns correctly in a short period of time. The participants indicated that they perceived the Hello.Wall as being an appropriate means of establishing awareness of people who were working at a remote site, thus overcoming the isolation of not being physically present without causing privacy problems.

The study participants described the Hello.Wall as providing a playful experience while interacting with the remote team. They commented that due to the Hello.Wall, interactions with the remote site took place more often, spontaneous video conference interactions were less formal, and videoconferencing became a daily routine.

The Hello.Wall patterns and their smooth movements when flowing over the display were considered to be aesthetically pleasing. People mentioned that the Hello.Wall caused positive feelings and induced a good mood.

Our future work will exploit the results gained in this study as we focus on building awareness support for distributed remote home environments in a new EU-funded project, Amigo–Ambient Intelligence for the Networked Home Environment (www.ipsi.fraunhofer.de/ambiente/amigo). ■

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