# Space Matters: Physical-Digital and Physical-Virtual Codesign in inSpace

Derek Reilly[1], Stephen Voida[2], Matt McKeon[3], Christopher Le Dantec[1], Jonathan Bunde-Pedersen[4], W. Keith Edwards[1], Elizabeth D. Mynatt[1], Ali Mazalek[1]
[1] GVU Center, Georgia Institute of Technology, Atlanta GA, USA
[2] University of California, Irvine, Irvine CA, USA
[3] IBM Research, T.J. Watson Research Center, Cambridge MA, USA
[4] IT University of Copenhagen, Copenhagen, Denmark

## Introduction

The inSpace project is an interdisciplinary collaboration between Georgia Tech and Steelcase Inc., bringing together expertise in human-computer interaction, ubiquitous computing infrastructure, industrial design, furniture and interior design, and architecture. A central goal in this research partnership is to understand how guiding principles in the design of the physical world should inform the design of the digital technologies and services that form the pervasive computing substrate in this spaces, and more importantly, how these two layers should be co-designed.

An interactive team room ('inSpace') was designed from the ground up following this physical-digital co-design philosophy. We believe that the products and experiences of the physical-digital co-design effort of inSpace can be further extended to physical-*virtual* cross-reality workspaces. In this article we give an overview of the products of the inSpace project, emphasizing the impact of co-design on our creation of a range of physical-digital artifacts, and its relevance to the design of hybrid physical-virtual spaces that represents the current phase of our project.

### The Case for Room-scale Physical/Digital Co-design

All too often, collaboration is constrained by the design of our collaborative spaces and disrupted by the kinds of information technologies in use. While people are experts at exchanging, annotating, and managing information, shifting the topic of conversation, and negotiating social boundaries, the spaces in which people

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collaborate and the technological substrate intended to support such collaboration are often brittle and difficult to adapt to a variety of social situations.

In many offices, collaboration spaces are geared toward formal presentations and small group meetings—and technological support is arrayed to support these assumed uses, even though these spaces may be used for a wide range of activities. These spaces are often laid out based on a traditional template: seating around a conference table with a projection surface mounted on a wall at one end and a projector placed on the table or mounted above it, teleconference equipment in the center of the table, and power outlets for laptop computers within reach of the table.

The physical and technical structure of these spaces neither reflects nor responds to the full range of social practices that occur within them, such as free-flowing design meetings, informal get-togethers, and break-away work. Such spaces are also generally physically and technically inflexible. Rearranging chairs can be difficult in a room dominated by a meeting table, and the dimensions of the table can make collaborating over large paper documents or sharing a computer interface problematic. Creating particular configurations of technology may require fumbling with cables (to connect a laptop to a projector) or manually moving information from one device to another (passing USB drives or copying files to and from network servers). The technical and physical infrastructure in these spaces is not fluid enough to support the information exchange and ad hoc reconfiguration that are necessary to facilitate collaboration.

Pervasive Computing has long sought to provide more flexible technological infrastructure, by creating innovative digital systems that fit into the physical environment to support the work that happens there. Examples include the iRoom[3], and RoomWare[4]. However, we argue that much of this work has focused less on how these digital technologies are embodied in the physical world, and become available for social appropriation and discourse.

The physical and social cues that we rely upon during collaboration— whether a particular person is getting ready to take the floor; whether someone is preparing to leave a meeting; whether a person is a longtime collaborator or a new partner from an outside organization—can vanish in the digital realm, where tangible affordances and feedback are often lost. While a network projector may do away with fumbling for cables, we lose the ability to identify the presenter at a glance; moreover, the social cue of reaching for a cable to signal a desire to present is also lost. These embodied social practices have implications *both* for the design of the technological infrastructure as well as for the design of the physical space itself.

## Physical-Digital Co-Design in InSpace

Our physical-digital co-design effort sought to address these issues by emphasizing the social behavior observed in collaborative spaces in our designs. Three broad guidelines were identified from the ethnographic work of our partners examining technology use in collaborative spaces. Each is discussed in this section:

- spaces and technologies should both reflect and respond to social practices;
- spaces and technologies should support fluidity in collaboration and information exchange; and
- spaces and technologies should have a social "voice" of their own. That is, their states and capabilities should be made manifest so that they can be understood and acted upon during collaborative activity.

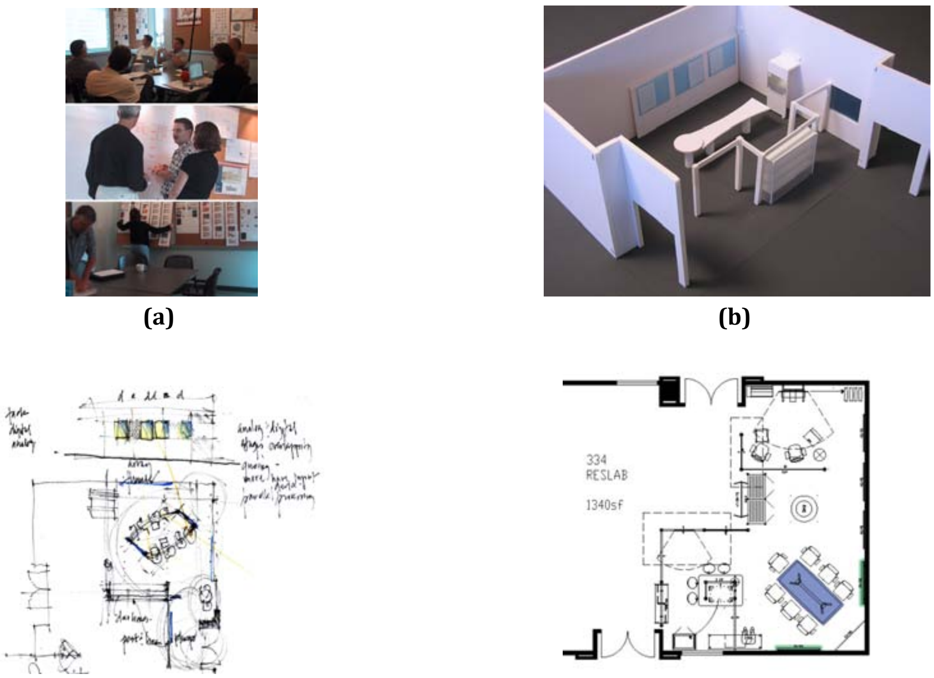
To situate this discussion, we also describe the influence of each guideline on three concrete physical-digital prototypes resulting from this work. Each prototype is also presented in a separate vignette accompanying this article (see Vignettes 1-3).

First and foremost, **social practices should drive design** of both space and technology. Grounding design in social practices is a well-established technique; our work builds on this by demonstrating how the distillation of social practices into a set of concrete "patterns" of social activity can provide common ground among members of an interdisciplinary design team, to better facilitate co-design.

This strategy was employed by the industry members of our team to derive a range of social patterns (in the sense of Alexander [1]) from ethnographic observation of real-world meetings, which were then used these to establish a common vocabulary with the computer scientists and interaction designers on our team. These patterns included "extended face-to-face engagement on a shared topic," "the pre-work of arriving at a meeting," "breaking away for a private exchange," "taking the floor for an extended turn," among a number of others. These patterns were used to structure an iterative design process for the inSpace environment, including both its physical design and the design of a number of digital services and devices meant to inhabit that space. This process relied extensively on paper prototyping and crude life-size mockups before arriving at the current design. Figure 1 depicts artifacts resulting from this design process, which we used to reflect upon the social patterns we wished to support.

For example, in the physical realm, the "pre-work", "extended engagement" and "breaking away" patterns directly translated into specific spatial configurations intended to support these practices, informally termed the "arrive", "assemble", and "aside" spaces. The inSpace Wall and Table prototypes (see Vignettes 1 and 2 []) work together to facilitate extended sharing of and collaboration over documents, and were designed alongside the "assemble" space, while the SpinSpace prototype (Vignette 3 []) permits the rapid acquisition of digital artifacts from elsewhere in the room, and was designed to work in a specific "aside" space. The patterns were also reflected in the software infrastructure supporting the room: for example, the "taking the floor" pattern influenced the design of information services that would better reveal how information was flowing among the devices in the space.

Our second design guideline was to emphasize the need for **fluidity** in both the physical and technical dimensions. After observing meeting participants moving among different styles of social interaction within a single meeting, we made it a priority to design an environment that supports users as they transition from one style of collaboration to another. In the physical realm, this took the form of easily




(a) (b) (c) (d)

**Fig. 1.** inSpace design artifacts, including (a) photographs captured during meeting observations, (b) foam-core mockups of the meeting room physical design and layout, (c) sketch-based analyses of space usage and spatial collaboration dynamics, and (d) plan view of the inSpace environment.

reconfigurable physical objects: for example, whiteboards slide easily; a portable interactive podium can be positioned as appropriate; shared displays are placed on arms or swivels (see Vignette 3), tables and chairs are on wheels. At the intersection between physical and digital, visual feedback on the main gathering table (see Vignette 1) facilitated exchange of control. In the digital realm, facilities were developed to permit and advertise the transitioning from one document set to another on a large shared display (see Vignette 2), and infrastructure was created that would automatically store the digital artifacts (such as presentations and images) exchanged among devices in the room, facilitating retrieval and reuse.

Our third guideline was that **technology must have a social voice** in the collaborative environment. Even invisible, digital services must make themselves accountable and intelligible in a way that allows them to be appropriated by social processes. This "voice" must be coherent and appropriate for the social context. In current projectors, for example, when the projector connection is embodied as a physical cable, participants may negotiate over it using the same cues they would use for any desirable shared resource. Not only must we ensure that these affordances are not lost when we move to digital services, we must also ensure that they are designed in a socially appropriate manner. In the inSpace environment, dynamically generated color cues embedded in the table identify actors and their actions relative to a shared wall display (see Vignettes 1 and 2). The SpinSpace display (Vignette 3) advertises its capability as a mechanism for "capturing" content for break-away work by virtue of its 180° pivot and see-through presentation of the digital content in the room. It is made further appropriate for break-away work by being dual-sided, and by its placement on a table with raised seating, offering equal opportunity for those sitting and standing.

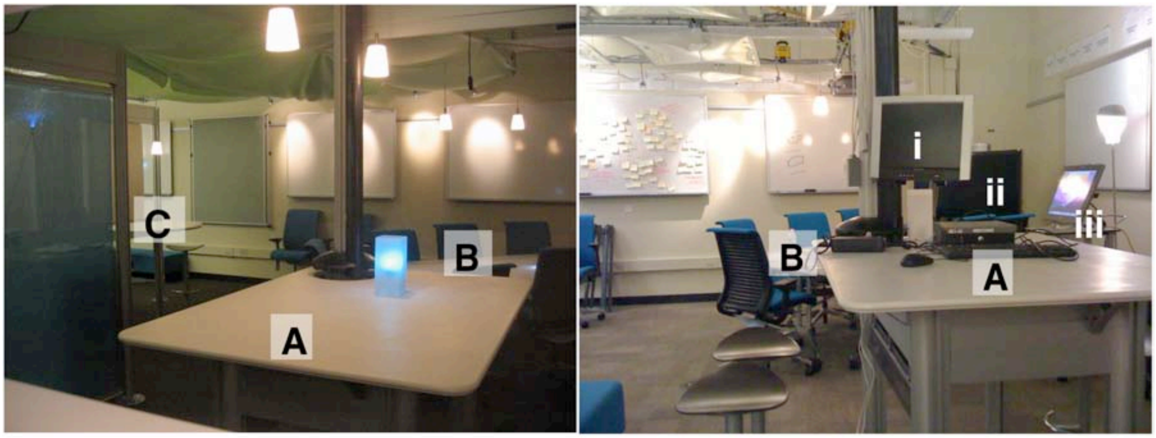



**Fig. 2.** The inSpace environment. Left: before installation of hardware. Right: after installation. A) the "arrive" space. B) the "assemble" space. C) the "aside" space designed with SpinSpace. i) kiosk display on a swiveling arm in the "arrive" space. ii) Wall display at head of the inSpace Table. iii) movable "podium" touch display.

The inSpace lab was iteratively designed and constructed over the course of 18 months in a laboratory space at Georgia Tech's GVU Center. The space was created to facilitate small group activities (6–10 participants) and has the following features (see figures 1, 2):

- an area for participants to congregate before and after meetings (the "arrive" space)
- a primary gathering area (the "assemble" space)
- semi-private areas for small group break-away sessions or for transitory individual work ("aside" spaces), and
- a room operating system that reflects and augments the social spatial vocabulary of inSpace.

The congregation area (Figure 2 (A)) was outfitted with a kiosk display mounted on a swiveling arm. Summary meeting data generated as an RSS feed from the room operating system's archive could be displayed on the kiosk, to facilitate engagement with a meeting already in progress, or to review previous activities before beginning a new meeting. The summary data includes temporal and spatial information that can be mapped to the semantics of the space: for example, if four documents were displayed simultaneously on a Wall (Vignette 2) and then one of those documents was transferred to SpinSpace (Vignette 3), the reader can infer that break-away work took place at that time. The swiveling display can also be rotated to face the participants in the primary gathering area. Finally, the area can itself be used as a larger space for break-away work.

The primary gathering area (Figure 2 (B)) consisted of the inSpace Table (see Vignette 1) and three inSpace Walls (see Vignette 2), one at the head of the table, and two projected on walls to either side. A touch display was provided on a moving, standing-height platform to facilitate "extended turns" such as formal presentations and lightweight collaborative activity without breaking away from the main group.

A circular table for break-away work was provided to one side of the primary area (Figure 2 (C)). The table is at standing height to facilitate transitory and active work, such that those seated and standing around the table are at eye-level, an important social cue in collaboration. In the center of the table is the SpinSpace display (see Vignette 3), which facilitated both the capture of digital artifacts displayed in other regions of the room and the fluid re-engagement with individuals in those regions.

The room's software infrastructure involves a message-oriented middleware framework similar in many respects to EventHeap [3] and other message-passing architectures for interactive rooms. In addition to events and commands, however, we specifically designed this infrastructure so that *content* also flows through the middleware layer. This was so that digital content exchanged among services could be captured "for free," and tagged with metadata describing the spatial and collaborative semantics of how it was used (for example, that a particular piece of content had been posted on the center Wall by one user, displayed for several minutes, and then transferred to another user's laptop). This combination of automated content capture and semantic tagging distinguishes inSpace from other systems such as Stanford's iRoom [3] and TeamSpaces [2], which use out-of-band mechanisms for most content exchange, and rely on user-generated metadata, as well as from meeting capture systems, which focus on the explicit capture of the audio-visual record of the meeting (for example, see [5,6]).

## Reflections

This first inSpace effort focused on physical-digital co-design in a single shared space, and leveraged an approach to co-design grounded in patterns of social behavior. These patterns guided not only the interior layout and furniture design of the space, but even the requirements for our underlying software infrastructure and the services built upon it. The "common ground" provided by these patterns served an essential role in supporting communication across an interdisciplinary design team.

By grounding our approach in the primacy of human activity and social patterns, we argue that the inSpace design represents a subtle divergence from a range of other pervasive "smart space"-type systems. Many such systems have traditionally focused on moving agency from social interactions into the supporting technology. For example, in the NIST smart space [6], EasyMeeting [7], and the SMaRT space at ISL [8], extensive sensing is put to work tracking individuals' locations in the space, identifying speakers by their voice, and performing speech recognition to identify spoken commands and capture person-to-person discussions in the space. These technologies are used to construct inferential representations of the context surrounding meetings to suggest service configurations [6], to automatically affect simple actions like starting presentations or dimming the lights [7], or to compile automatic summaries of meetings [8].

In inSpace, rather than relying on ubiquitous low-level sending and inference of user intent, users retain agency, explicitly controlling the flow of information and the transition between social patterns. Sensing, when it was used in our system, was embedded into the room-scale tools (e.g., the Table and SpinSpace), rather than throughout the room. Correspondingly, the meaning of interactions with digital artifacts was rendered more comprehensible through association with the situated tools in the space, rather than by automated contextual reasoning. Tying these approaches together was the archiving and tagging infrastructure that associated spatial and semantic metadata to shared digital artifacts.

We argue that while the move to networked, digital services will provide new capabilities for collaborative workspaces, these may come with the loss of physical affordances and feedback. By augmenting furniture to provide context for otherwise invisible uses of technologies in the room, we have attempted to add some of the physicality back to these interactions without sacrificing the advantages gained by wireless and ubiquitous technologies. This approach to physical-digital co-design engendered a fruitful middle ground: the creation of technology that was neither invisible nor anthropomorphically intelligent, but played a role in the social shaping of a space. By giving both space and technology a social voice, the furniture and services in the room enable rather than prohibit fluidity in collaborative activities.

## Looking Forward: Physical-Virtual Co-design

Our first full design iteration of inSpace produced a range of physical and digital artifacts in a single workspace. Looking forward, we wish to explore the same approach to socially-grounded co-design in the development of hybrid physical-*virtual* spaces for collaboration. One key distinction between this work and the earlier phase of inSpace is that we aim to connect the physical and digital artifacts in the meeting space to *remote* collaborators who participate through a virtual world (Figure 3), in our case Sun's Wonderland virtual world engine [9].

### Motivation

Using a virtual world holds several potential benefits over teleconferencing: it provides equal opportunity for participation no matter where one is, it offers a common 'meeting place' for casual encounters, and can provide shared spatial reference points for collaboration over digital artifacts. A number of projects and commercial products have employed virtual worlds to support distributed collaborative work. Second Life, while designed as a primarily social virtual world, has been used for business events, presentations, lectures and meetings. Project Wonderland [9], Croquet [10], and commercial products such as OLIVE and Qwak Forums provide virtual environments with support for collaboration over digital media. As more collaborative work moves onto these platforms, we must consider their impact on the physical spaces intended for co-located collaboration.

While the integration of virtual worlds with physical meeting spaces is a promising design opportunity for mixed presence groupware, it also poses many challenges.

To illustrate, we briefly describe our own experiences conducting design and brainstorming meetings using the inSpace environment and a virtual meeting room in Wonderland, without special effort to link the two spaces (see Figure 3). Despite presenting a view of Wonderland in the field of view of meeting room participants, it was difficult to maintain awareness of activities in the virtual world, especially during extended meetings. Since the virtual world provides a low-bandwidth medium for non-verbal social cues, audio became essentially the sole method of communicating with remote participants. Co-present and remote participants often felt like distinct groups: when virtual world participants didn't speak for an extended period, meeting room participants could forget they were there. Meanwhile, virtual world participants communicated with each other using a text chat backchannel that was often ignored by meeting room participants. Placing content in the virtual world refocused attention to the virtual world, however to maintain legibility such documents were displayed in a 'best view' that largely cut out all other virtual world content and avatars.

Our goal is to understand how these two connected spaces—the physical room and the virtual world—can be co-designed to better support collaboration. As emphasized in the first phase of the inSpace project, physical space is imbued with meaning and social affordance via architectural design; groups, in turn, appropriate spaces based on the utility implicit in their form. By co-designing physical and digital infrastructure we have built on the cues of architectural form, reflecting spatial meaning and social action back to the group, amplifying and augmenting group activity. Physical-virtual co-design should permit similar kinds of amplifications, awareness cues and interactive consistencies that were explored in the single-room iteration of inSpace.

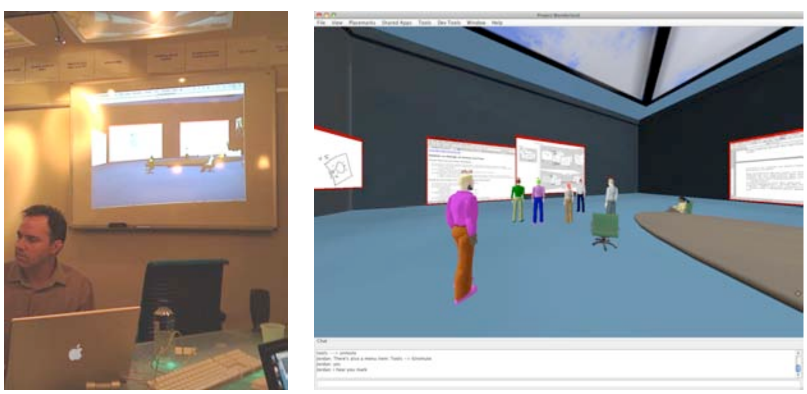


**Fig. 3.** Brainstorming the new inSpace effort in the inSpace lab (left), and simultaneously from within Wonderland (right). Avatars are positioned to view a set of documents that were built and/or referred to during brainstorming.

## Guidelines for physical-virtual co-design

We are beginning our new co-design effort by using the inSpace environment as a launching point for design inspiration, and by revisiting the three broad guidelines driving the physical-digital work. In this section we revisit each guideline, reflecting on how each might influence physical-virtual co-design. To ground the discussion we sketch a design of a physical-virtual "podium" that applies these guidelines.

*Spaces and technologies should both reflect and respond to social practices*

When mapping a virtual space to a designed space, a faithful spatial correspondence may not be necessary—it is most important that the social meaning of actions within the space are communicated, and that opportunities for collaborating across realms are promoted. The potential to decouple spatial organization is valuable: it permits the virtual space to be designed according to the capabilities offered by the medium, and allows multiple spaces with different organizations to be fused together in a meaningful way, whether they be physical or virtual.

Focusing on the collaboration semantics and designed affordances of a space rather than the spatial configuration itself permits the establishment of meaningful "contact-points" between the virtual and the real. For example, the "the pre-work of arriving at a meeting" may be facilitated by offering a navigable view into a virtual lobby in the "arrive" space in the inSpace environment while simultaneously advertising your arrival to those in the virtual world.

In our design sketch (Vignette 4), the Podium serves as a contact point suitable for giving presentations and taking 'extended turns' in a collaborative exchange. It is a "dual-presence entity", equally accessible to virtual and physical participants, with similar controls offered in both realms. The podium may have a "best orientation", that is to face the other participants in the virtual and physical environments, but this spatial constraint can be realized without requiring the two spaces to be structured in the same way.

*Spaces and technologies should support fluidity in collaboration and information exchange*

We believe that fluidity is paramount in mixed physical-virtual collaboration. For example, we anticipate that physical-virtual collaboration will require the ability to fluidly change the nature of contact points to benefit collaboration: that is, this kind of collaboration will require scalable and *configurable* connectivity. We have been considering the current inSpace environment to explore this need. Informal discussion over several documents may benefit from the presentation of these documents on the Wall on one end of the inSpace Table, while contextual windows into the virtual environment are presented on the peripheral projected displays to indicate how remote participants are viewing the same documents. In contrast, focused collaboration over a single document may foreground that document in the physical space and require different kinds of contextual information (e.g. cues to promote awareness of agency for participants in both realms).

The Podium (Vignette 4) gives strong cues to its use as a presentation tool. Its presence in an interactive cross-reality environment suggests opportunities to apply its basic affordances in new ways, however. For example, the podium offers control over the selection and arrangement of documents in both spaces, and so could serve as a common centralized controller, or as a tool to interact with specific subsets of physical/virtual displays. Virtuality can help promote fluidity: in these examples the

Podium would likely not be represented as “a podium” in the virtual world, if it is represented at all.

*Spaces and technologies should have a social voice of their own*.

During active collaboration in a physical room, the presence and activity of others in a virtual room needs to be evident,. One way to achieve this is by extending the collaboration vocabulary designed for the physical inSpace room out to the virtual team room: for example, avatars of virtual participants who are uploading documents for sharing might be displayed with a halo of coloured dots in an equivalent manner as individuals seated at the inSpace Table. Additionally, participants in the virtual world may need some indication that artifacts in the physical room are being reconfigured. We have outfitted the inSpace environment with RFID carpet tile in anticipation of this. It is interesting that certain physical-virtual mappings may require pervasive, low-level sensing to accomplish, whereas physical-digital co-design did not.

The Podium (Vignette 4), by being situated in the primary gathering space, provides a visual indicator that someone in the virtual space wants an extended turn during a meeting. In this sense it serves as a way for people in either the physical or virtual team room to advertise intent in both realms at once. By tracking the position and orientation of the podium in the physical room, we can also position the virtual representation in a complementary fashion: facing avatars when the podium faces the inSpace Table, and facing mapped content when the podium faces content on an inSpace Wall.

## Summary

Our first foray into physical-virtual co-design has been to use the inSpace environment as a ‘jumping off point’ for inspiration. inSpace, because it is grounded in primacy of human activity and social patterns, contains features that may facilitate communication *across* spaces. We argue that the guidelines motivating the physical-digital co-design phase of the inSpace project extend to physical-virtual co-design. By embodying similar collaborative spatial semantics in the physical and virtual and exploiting this in contact points, by supporting fluid transitions between physical-virtual mappings, and by using a common social vocabulary across realms to promote awareness, we believe that physical-virtual co-design can extend spatial meaning into virtual spaces and facilitate mixed physical-virtual collaboration.

## Acknowledgments

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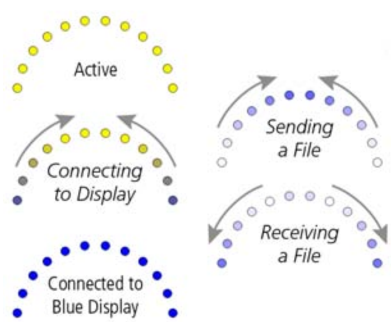
## Vignettes

### InSpace Table

**(a)**




**(b)**

**Fig. 4.** Lighting feedback on the inSpace Table. (a) Feedback indicating that the laptop computer is connected to the meeting room. (b) Selected lighting animations used by the table.

The inSpace Table was designed to promote fluid transitions between personal workspace (laptops and other personal devices) and the shared workspace (wall displays). This was accomplished by giving personal devices a means to express their relationship to the physical and information environments [4]. Meeting participants place devices or objects on the table to bring them into the context of the meeting. A software service running on the client devices is informed of its connection to the table (using RFID), which allows it to discover other services on the table, and in the room; the table also provides the client device with its physical position on the table. Once connected, devices on the table display a GUI with a spatial representation of the room and controls for accessing other services and devices in the meeting. Further, the table provides ambient feedback on activity involving devices on the table via lighting effects visible through the table's surface.

### InSpace Wall

**Fig. 5.** An inSpace Wall, displaying artifacts shared by three meeting participants. The meeting participant represented by the green color is currently uploading a new file to the Wall, indicated by the status bar display at the lower left.

inSpace Walls are large display surfaces with software that facilitates collaboration over shared artifacts, such as documents, images, videos, and shared windows. When a laptop is placed on the table, a client application appears on the laptop, allowing users to select and connect to a Wall for sharing information (such as images, slides, and so forth).

The Wall display presents multiple thumbnails representing the artifacts sent to it by connected devices (Figure 5). Unlike a standard VGA projector, multiple parties can be connected at the same time, and screen real estate is *fluidly* managed to display information from each. Contents are grouped according to owner and tiled throughout the Wall's display space.

## SpinSpace

**Fig. 6.** SpinSpace design sketches (left and center), and the resulting design in the inSpace environment (right).

SpinSpace is a two-sided spinning screen [11] equipped with touch-screen functionality. SpinSpace facilitates the formation of sub-teams, within the context of the meeting room, to discuss details regarding the larger on-going discussion or presentation. SpinSpace is situated in the center of a circular table configuration designed for break-away work. The SpinSpace interface provides a situated camera view of the inSpace environment, such that content may be transferred between SpinSpace and an inSpace Wall by rotating the SpinSpace display so that the desired Wall is in its field of view. Once content is selected, it is presented on both sides of the display so that all members of the sub-group can work with the information.

## TwinSpace Podium (design sketch)

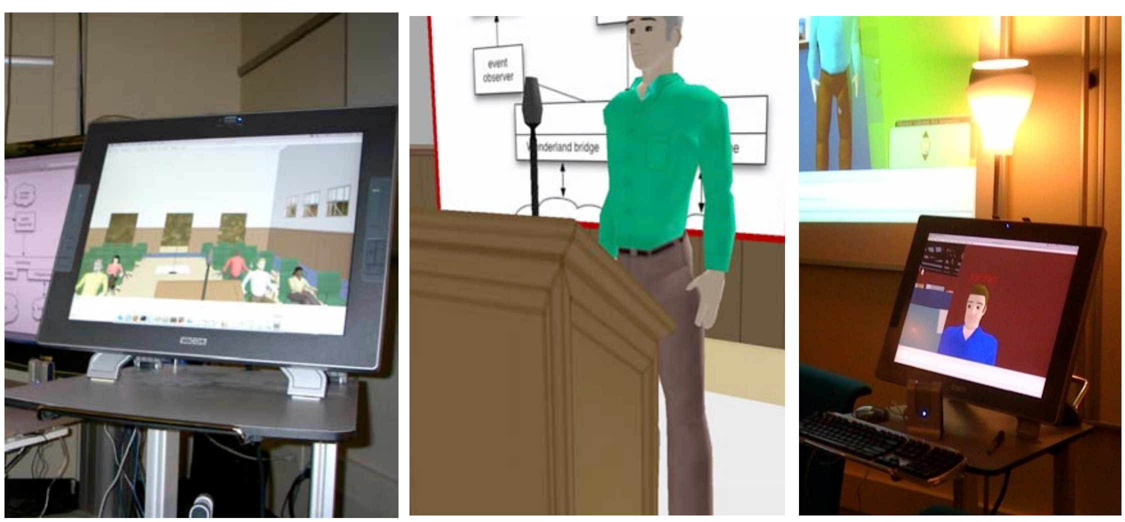



**Fig. 7.** The TwinSpace Podium design concept. Hardware in teamroom (left), representation in virtual world (center), and the Podium appropriated as a communication portal (right).

The TwinSpace Podium is a mobile, dual-presence, touch-screen presentation kiosk. The kiosk's primary function is a presenter's station: presentations are controlled via the kiosk and displayed simultaneously on large displays in a physical meeting room and in a virtual world. The kiosk has "dual presence": there is a representation of it in the virtual world that is fused to the physical device in several ways. If the presenter is in the physical room, his/her avatar is shown at the virtual kiosk. Likewise, if the presenter is in the virtual world, his/her avatar is represented on the display of the physical kiosk. Finally, the kiosk is mobile: it can be rotated and moved in the physical room. When the physical room and virtual room are configured in a complementary way, moving the kiosk serves as a means of setting up the virtual location of the kiosk or establishing a sense of where the kiosk is (virtually) located.