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

The physical and social cues we rely on during collaboration can vanish in the digital realm. inSpace considers codesign of physical spaces, virtual spaces, and digital services, leveraging an approach grounded in social behavior patterns.

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The inSpace project is an interdisciplinary collaboration between the Georgia Institute of Technology and Steelcase, bringing together expertise in human-computer interaction, ubiquitous computing infrastructure, industrial design, furniture and interior design, and architecture. inSpace has two central goals. The first 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 these spaces. The second and more important goal is to understand how to codesign these two layers.

Following this physical-digital codesign philosophy, we designed an interactive team room from the ground up. We believe that the products and experiences of this research extend to physical-virtual cross-reality workspaces.

The Case for Room-Scale Physical-Digital Codesign

All too often, collaboration is constrained by our collaborative spaces' design and disrupted by the kinds of information technologies in use. People are experts at exchanging, annotating, and managing information; shifting the topic of conversation; and negotiating social boundaries. However, the spaces in which people collaborate and the technological substrate intended to support such collaboration are often brittle and difficult to adapt to various social situations.

In many offices, collaboration spaces are geared toward formal presentations and small-group meetings. So, the associated technology is arrayed to support these assumed uses, even though people might use these spaces for a range of activities. These spaces' layouts are often based on a traditional template:

- seating around a conference table, with a projection surface on a wall at one end and a projector on or above the table,
- teleconference equipment in the center of the table, and
- power outlets for laptop computers within reach of the table.

These spaces' physical and technical structures neither reflect nor respond to the full range of social practices that occur in them, such as free-flowing design meetings, informal get-togethers, and breakaway 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 table dimensions can make collaborating over large paper documents or sharing a computer interface problematic. Creating par-

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ticular configurations of technology might require fumbling with cables—for example, to connect a laptop to a projector—or manually moving information from one device to another, such as passing USB drives or copying files to and from network servers. The technical and physical infrastructure in these spaces isn't fluid enough to support the information exchange and ad hoc reconfiguration necessary to facilitate collaboration.

Pervasive computing researchers and system developers have long sought to provide more flexible technological infrastructure by creating innovative digital systems, such as the iRoom[1] and RoomWare,[2] that fit in the physical environment to support the work that happens there. However, little of this research has focused on how these digital technologies are embodied in the physical world and become available for social appropriation and discourse.

The physical and social cues on which we rely during collaboration—for example, whether a particular person is getting ready to take the floor or preparing to leave a meeting, or 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. Although a network projector might 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 lost. These embodied social practices have implications for both technological-infrastructure and physical-space design.

Physical-Digital Codesign in inSpace

We sought to address these issues by emphasizing the social behavior observed in collaborative spaces. We identified three broad guidelines from our partners' ethnographic work examining technology use in collaborative spaces. These guidelines influenced three concrete inSpace physical-digital prototypes: the inSpace Table, the inSpace Wall, and SpinSpace (see the "inSpace Prototypes" sidebar).

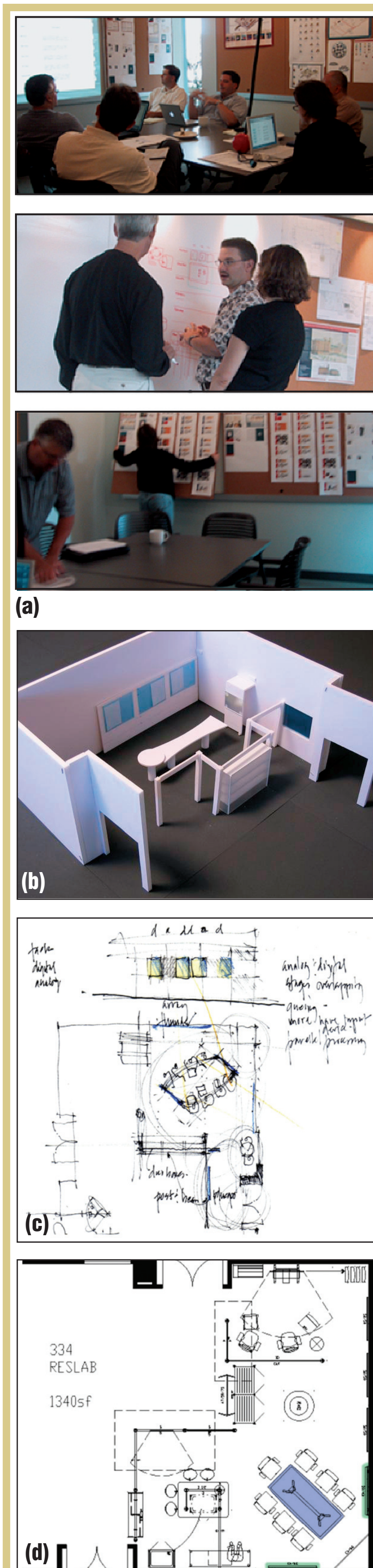


Figure 1. inSpace design artifacts. We designed the inSpace environment and its digital services to support several distinct collaborative work patterns identified through ethnographic observation of meeting practices. (a) Photographs captured during meeting observations. (b) Foam-core mockup of the meeting room's physical design and layout. (c) Sketch-based space-usage and spatial-collaboration-dynamics analyses. (d) A plan view of the inSpace environment.

Social Practices Are the Key

First and foremost, social practices should drive both space and technology design. 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 social activity patterns can provide common ground among members of an interdisciplinary design team, to better facilitate codesign.

Our team's industry members employed this strategy to derive a range of social patterns[3] from ethnographic observation of real-world meetings. We then used these patterns to establish a common vocabulary with our team's computer scientists and interaction designers. The patterns included "extended face-to-face engagement on a shared topic," "the prework of arriving at a meeting," "breaking away for a private exchange," and "taking the floor for an extended turn." We used these patterns to structure an iterative design process for the inSpace environment, including both its physical design and the design of several digital services and devices meant to inhabit that space. This process relied extensively on paper prototyping and crude life-size mockups before we arrived at the current design.

inSpace Prototypes

We created four prototypes to facilitate technology use in collaborative spaces. The inSpace Table, inSpace Wall, and SpinSpace display resulted from our physical-digital codesign effort in the first phase of the inSpace project. The Podium is one early product of our current physical-virtual codesign work.

The inSpace Table

We designed the inSpace Table to promote fluid transitions between personal workspace (laptops and other personal devices) and shared workspace (wall displays). We accomplished this by giving personal devices a means to express their relationship to the physical and information environments.[1]

Meeting participants place devices or objects on the inSpace Table to bring them into the meeting's context. A software service running on the client device is informed of its connection to the inSpace Table (using RFID). This lets it discover other services on the inSpace Table and in the room and provides the client device with its physical position on the inSpace Table. Once connected, devices display a GUI with a spatial representation of the room and controls for accessing other services and devices in the meeting. Furthermore, the inSpace Table provides ambient feedback on activity involving devices on it via lighting effects visible through its surface (see Figure A).

The inSpace Wall

The inSpace Wall is a large display surface with software that facilitates collaboration over shared artifacts (see Figure B). When a participant places a laptop on the inSpace Table, a client application appears on the laptop, letting users select and connect to the inSpace Wall to share information such as documents, images, videos, and windows.

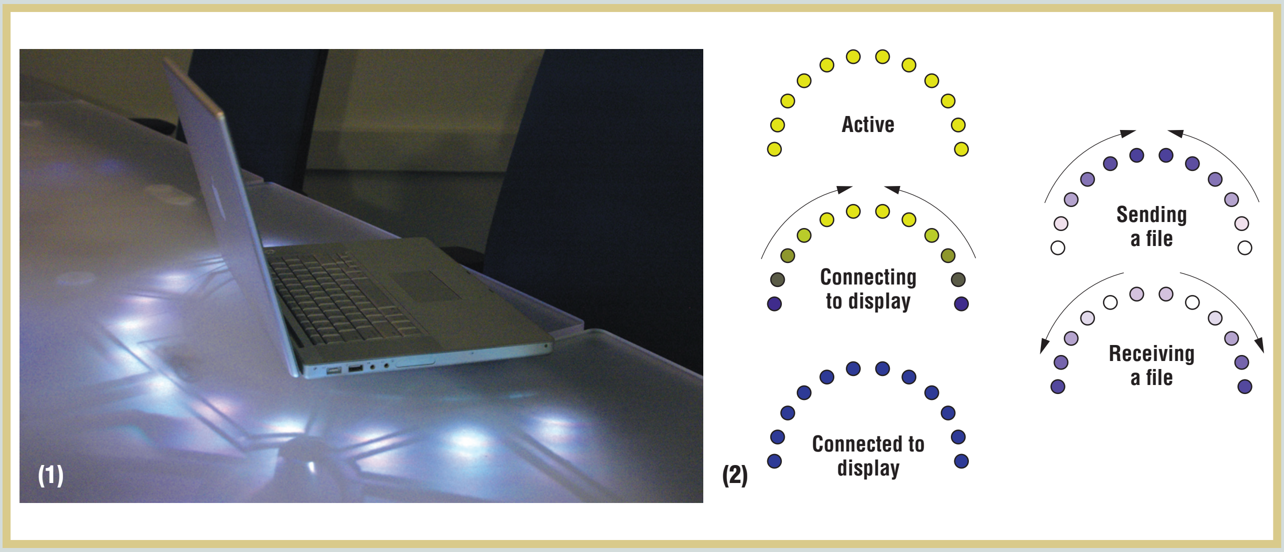
The inSpace Wall presents multiple thumbnails representing the artifacts sent to it by connected devices. Unlike with a standard VGA projector, multiple parties can be connected at the same time, and screen real estate is fluidly managed to display information from each. Contents are grouped according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

SpinSpace

This two-sided spinning screen[2] incorporates touch-screen functionality (see Figure C). SpinSpace facilitates the formation of subteams, in the context of the meeting room, to discuss details regarding the larger ongoing discussion or presentation.

We placed SpinSpace in the center of a circular table configuration designed for breakaway work. The SpinSpace interface provides a situated camera view of the inSpace environment. Participants can transfer content between SpinSpace and an inSpace Wall by rotating the SpinSpace display so that the desired inSpace

Figure A. Lighting feedback on the inSpace Table. (1) Feedback indicates that the laptop computer is connected to the meeting room. (2) Selected lighting animations used by the inSpace Table. The inSpace Table promotes fluid transitions between personal and shared workspaces.



Wall is in their field of view. Once content is selected, it appears on both sides of the display so that all the subgroup members can work with it.

The Podium

This mobile touch-screen presentation kiosk functions primarily as a presenter's station (see Figure D). Presentations are controlled via the kiosk and displayed simultaneously on large displays in both the physical meeting room and a virtual world.

The kiosk has dual presence—its representation in the virtual world is fused to the physical device in several ways. If the presenter is in the physical room, the virtual kiosk shows his or her avatar. If the presenter is in the virtual world, the physical kiosk displays the avatar.

Finally, the kiosk is mobile: participants can rotate and move it in the physical room. When the physical and virtual rooms are configured in a complementary way, moving the kiosk serves as a means of setting up its virtual location or establishing a sense of where it's (virtually) located.

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Figure B. An inSpace Wall, displaying artifacts shared by three meeting participants. A meeting participant (green) is uploading a new file to the inSpace Wall, indicated by the status bar on the lower left.

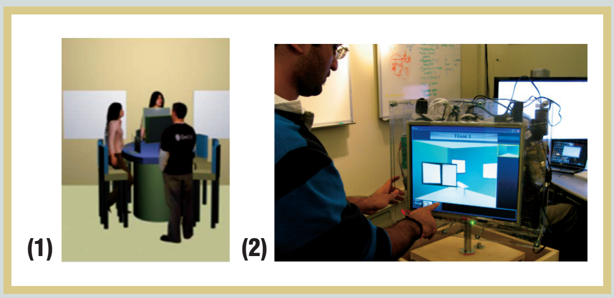

Figure C. SpinSpace, a two-sided spinning screen with touch-screen functionality. (1) Design sketch. (2) The resulting design in the inSpace environment. SpinSpace facilitates the formation of subteams to discuss details regarding the larger ongoing discussion or presentation.

Figure D. The Podium, a mobile, dual-presence, touch-screen presentation kiosk. (1) The hardware in the team room. (2) The representation in the virtual world. (3) The Podium appropriated as a communication portal.

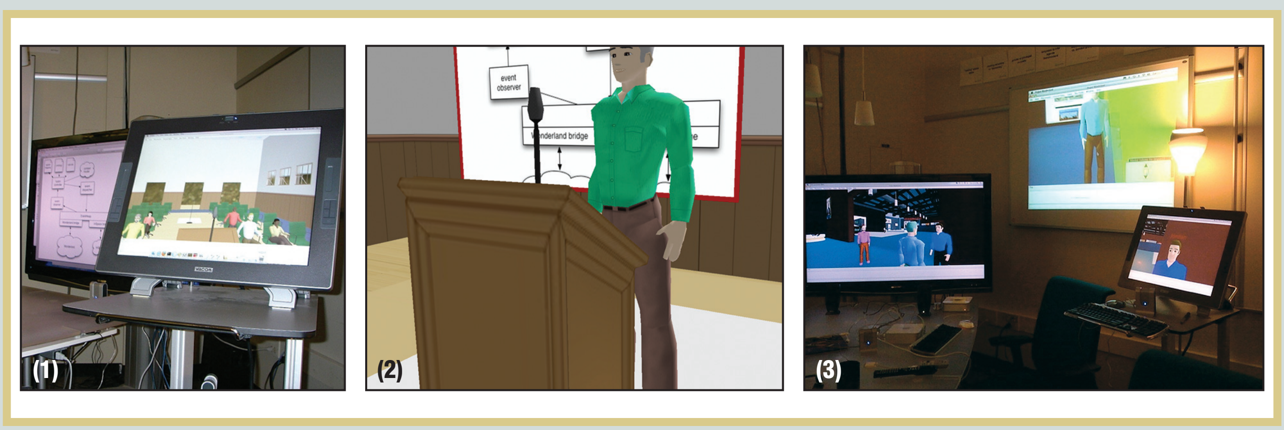

Figure 1 depicts artifacts of this design process, which we used to reflect on the social patterns we wished to support. For example, in the physical realm, the prework, extended-turn, and breaking-away patterns directly translated into specific spatial configurations intended to support these practices, informally termed the *arrive*, *assemble*, and *aside* spaces. The inSpace Wall and Table prototypes work together to facilitate extended sharing of and collaboration over documents and were designed alongside the assemble space. In contrast, the SpinSpace prototype permits the rapid acquisition of digital artifacts from elsewhere in the room and was designed to work in a specific aside space. The software infrastructure supporting the room also reflects these patterns—for example, the taking-the-floor pattern influenced the design of information services that would better reveal how information flowed among the devices in the space.

Emphasize Fluidity

Our second guideline was to emphasize the need for fluidity in both the physical and technical dimensions. After observing meeting participants moving among different social-interaction styles in a single meeting, we made it a priority to design an environment that supports users as they transition between collaboration styles.

In the physical realm, this took the form of easily reconfigurable physical objects—whiteboards slide easily, people can position a portable interactive podium as appropriate, shared displays are on arms or swivels, and tables and chairs are on wheels. At the intersection between the physical and digital, visual feedback on the main gathering table facilitated exchange of control.

In the digital realm, we developed facilities to permit and advertise the transition between document sets on a large shared display. We also created infrastructure that would automatically store the digital artifacts (such as presentations and images) exchanged among devices in the room, thus facilitating retrieval and reuse.

Technology Needs a Social Voice

Our third guideline was that technology must have a social voice in the collaborative environment. Even when they're invisible, digital services must make themselves accountable and intelligible in a way that lets them be appropriated by social processes. This voice must be coherent and appropriate for the social context. For example, currently, when the projector connection is embodied as a physical cable, participants can negotiate over it using the same cues they would use for any desirable shared resource. We must ensure not only that these affordances aren't lost when we move to digital services but also that they're designed in a socially appropriate manner.

In the inSpace environment, dynamically generated color cues embedded in the inSpace Table identify actors and their actions relative to a shared inSpace Wall display. For example, when a participant posts a document onto the shared display from a laptop, an animated semicircle of lights appears around the laptop, indicating that this individual is uploading (and sharing) the document. SpinSpace advertises its ability to capture content for breakaway work by virtue of its 180-degree pivot and see-through presentation of the digital content in the room. We made it dual sided, and thus even more appropriate for breakaway work, and placed it on a table with raised seating to offer equal opportunity for those sitting and standing.

We created infrastructure that would automatically store the digital artifacts exchanged among devices in the room.

The inSpace Setup

We iteratively designed and constructed inSpace over 18 months in a laboratory space at Georgia Tech's Graphics, Visualization, and Usability Center. To facilitate small-group activities (six to 10 participants), inSpace has these features:

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

We outfitted the arrive space with a kiosk display on a swiveling arm (see Figure 2). Summary meeting data generated as an RSS feed from the room operating system's archive can be displayed on the kiosk to facilitate engagement with a meeting in progress or to review previous activities before beginning a meeting. This data includes temporal and spatial information that can be mapped to the space's semantics. For example, if four documents are displayed simultaneously on an inSpace Wall and one of those documents is transferred to SpinSpace, the reader can infer that breakaway work took place at that time. The swiveling display can also rotate to face the participants in the assemble space. Finally, the arrive space can serve as a larger space for breakaway work.

The assemble space consists of

Figure 2. The inSpace environment (a) before and (b) after hardware installation: the (1) arrive space, the (2) assemble space, and the (3) aside space. The hardware installation includes a (4) kiosk display on a swiveling arm in the arrive space, an (5) inSpace Wall display at the head of the inSpace Table, and a (6) movable Podium touch display.

the inSpace Table and three inSpace Walls—one at the head of the table and two projected on walls on either side. We provided a touch display on a moving, height-adjustable platform to facilitate extended turns, such as formal presentations and lightweight collaborative activity, without breaking away from the main group.

A circular table for breakaway work is on one side of the assemble space. 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 table's center is SpinSpace, which facilitates both the capture of digital artifacts displayed in other sections of the room and fluid reengagement with individuals in those sections.

The room's software infrastructure involves a message-oriented middleware layer similar to EventHeap[1] and other message-passing architectures for interactive rooms. We designed this layer so that, in addition to events and commands, content flows through it. This lets users capture the digital content exchanged among services "for free" and tag it with metadata describing the spatial and collaborative semantics of how it was used. For example, this tagging could show that a particular piece of content had been posted on the center inSpace Wall by one user, displayed for several minutes, then transferred to another user's laptop. This combination of automated content capture and semantic tagging distinguishes inSpace from other systems such as the iRoom and TeamSpaces,[4] which use out-of-band mechanisms for most content exchange and rely on user-generated metadata, and from meeting-capture systems, which focus on the explicit capture of the meeting's audiovisual record.[5,6]

Reflections

inSpace focuses on physical-digital codesign in a single shared space, leveraging an approach grounded in social behavior patterns. These patterns guided not only the interior layout and furniture design of the space but even the requirements for the software infrastructure and the services built on it. The common ground these patterns provided was essential in supporting communication across the inSpace project's interdisciplinary design team.

The inSpace design represents a subtle divergence from a range of other pervasive "smart space" systems. Many such systems have traditionally focused on moving agency from social interactions into the supporting technology. For example, the US National Institute of Standards and Technology smart space,[6] EasyMeeting,[7] and the SMaRT (Smart Meeting Room Task) space[8] use sensing extensively to track individuals' locations, identify speakers by their voice, and perform speech recognition to identify spoken commands and capture person-to-person discussions. The systems use these sensing technologies to construct inferential representations of the context surrounding meetings to suggest service configurations,[6] automatically effect simple actions such as starting presentations or dimming the lights,[7] or automatically compile meeting summaries.[8]

Rather than relying on ubiquitous low-level user intent sensing and inference, inSpace lets users retain agency, explicitly controlling information flow and the transition between social patterns. We embedded sensing into the room-scale tools—for example, the inSpace 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, which associated spatial and semantic metadata to shared digital artifacts.

Although the move to networked, digital services will provide new capabilities for collaborative workspaces, these might come at the loss of physical affordances and feedback. By augmenting furniture to provide context for otherwise invisible uses of technologies in the room, we've tried 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 codesign engendered a fruitful middle ground: the creation

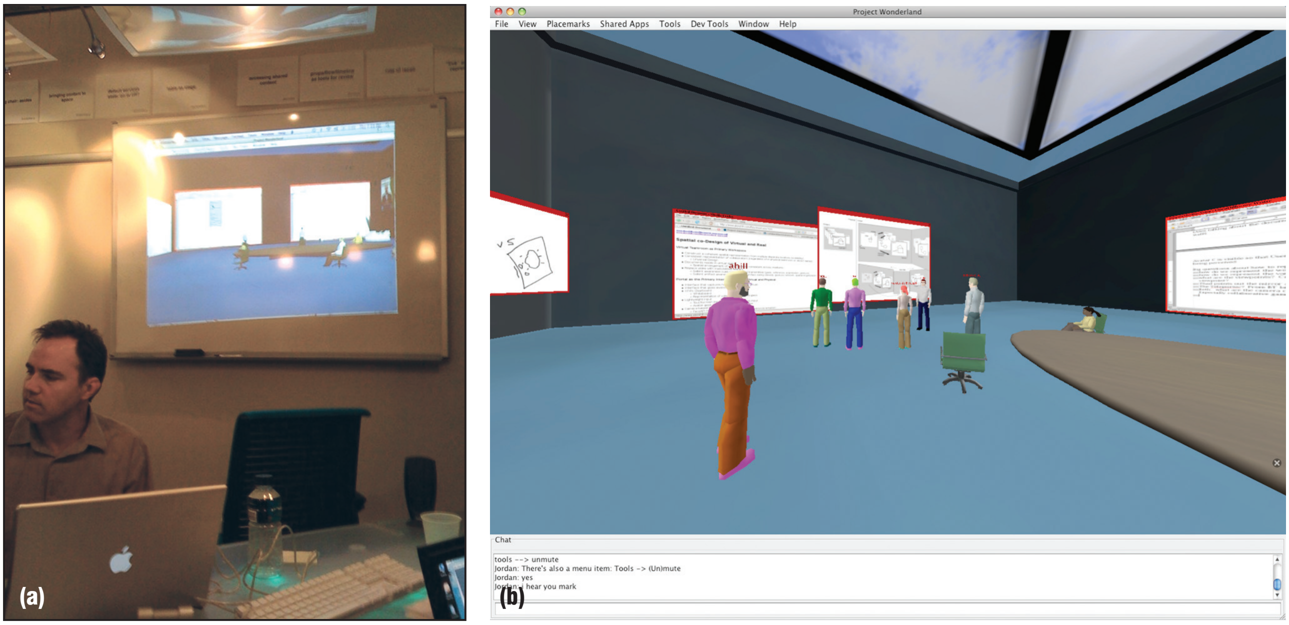

Figure 3. Brainstorming new inSpace research in (a) the inSpace lab and (b) simultaneously from within the Wonderland virtual world. Avatars are positioned to view a set of documents that were built or referred to during brainstorming. This stage of the inSpace project aims to connect the meeting space's physical and digital artifacts to remote collaborators who participate through a virtual world.

of technology that was neither invisible nor anthropomorphically intelligent but that played a role in the social shaping of a space. Because both the space and technology have a social voice, the furniture and services in the room enable rather than prohibit fluidity in collaborative activities.

Looking Forward: Physical-Virtual Codesign

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 codesign in the development of hybrid physical-virtual spaces for collaboration. One key distinction between this research and the earlier phase of inSpace is that we aim to connect the meeting space's physical and digital artifacts to remote collaborators who participate through a virtual world (see Figure 3). For this research, we chose the Open Wonderland virtual-world engine (www.openwonderland.org).

Motivation

Using a virtual world has three potential benefits over teleconferencing. First, it provides equal opportunity for participation no matter where you are. Second, it offers a common meeting place for casual encounters. Finally, it can provide shared spatial reference points for collaboration over digital artifacts.

Several research projects and commercial products have employed virtual worlds to support distributed collaborative work. Although designed as a primarily social virtual world, Second Life has been used for business events, presentations, lectures, and meetings. Project Wonderland, Croquet,[9] and commercial products such as Olive (On-Line Interactive Virtual Environment) and Qwak Forums provide virtual environments that support collaboration over digital media. As more collaborative work moves onto these platforms, we must consider their impact on the physical spaces intended for colocated collaboration.

Although the integration of virtual worlds with physical meeting spaces is a promising design opportunity for mixed presence (remote and colocated) collaboration, it poses many challenges. To illustrate, we briefly describe our experiences conducting design and brainstorming meetings using the inSpace environment and a virtual meeting room in Wonderland. Importantly, the meetings were conducted without any special effort to link the physical and virtual environments other than displaying a virtual-world client on a large display at one end of the meeting table.

Even though we presented Wonderland in the meeting-room participants' field of view, maintaining awareness of activities in the virtual world was difficult, especially during longer meetings. Because the virtual world provides a low-bandwidth medium for nonverbal social cues, audio became essentially the sole method of communicating with remote participants when the conversation's focus moved away from documents placed in the virtual world. Colocated 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, the virtual-world participants communicated with each other using a text chat backchannel that the meeting-room participants often ignored. Placing content in the virtual world refocused attention on 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 to codesign these two connected spaces—the physical room and the virtual world—to better support collaboration. As the first phase of the inSpace project emphasized, physical space is imbued with meaning and social affordance via architectural design. Groups, in turn, appropriate spaces on the basis of the utility implicit in their form. By codesigning physical and digital infrastructure, we've built on architectural form cues, reflecting spatial meaning and social action back to the group to amplify and augment group activity. Physical-virtual codesign should permit similar kinds of amplifications, awareness cues, and interaction consistencies that were explored in the single-room iteration of inSpace.

Guidelines for Physical-Virtual Codesign

We're beginning our physical-virtual codesign effort by using inSpace as a launching point for design inspiration and revisiting the three broad guidelines driving our physical-digital research.

Social practices are the key. When mapping a virtual space to a designed space, a faithful spatial correspondence might not be necessary. The most important thing is that the system communicates the social meaning of actions in the space and promotes opportunities for collaborating across realms. The potential to decouple spatial organization is valuable. It lets us design the virtual space according to the capabilities the medium offers and meaningfully connect spaces that are organized differently, whether they're physical or virtual.

Focusing on the collaboration semantics and designed affordances of a space rather than spatial layout alone permits the establishment of meaningful contact points between the virtual and the real. For example, you can facilitate "the prework of arriving at a meeting" by offering a navigable view into a virtual lobby in the arrive space in the inSpace environment while advertising the arrival to those in the virtual world.

In one of our early design sketches, we describe a touch-screen presentation kiosk we call the Podium, which serves as a contact point suitable for giving presentations and taking extended turns in a collaborative exchange (see the "inSpace Prototypes" sidebar). It's a "dual-presence entity," equally accessible to virtual and physical participants, with similar controls offered in both realms. The Podium might have a "best" orientation—that is, facing the audience members in both the virtual and physical environments. However, this constraint can be realized without requiring the two spaces to have the same spatial layout.

Emphasize fluidity. We believe that fluidity is paramount in physical-virtual collaboration. For example, we anticipate that such 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, configurable connectivity between real and virtual spaces.

We've been using the current inSpace environment to explore this need as well. Informal discussion over several documents might benefit from the presentation of these documents on the inSpace Wall display on one end of the inSpace Table. At the same time, contextual windows into the virtual environment could appear on peripheral projected displays to indicate how remote participants are viewing the same documents. In contrast, focused collaboration over a single document might foreground that document on the inSpace Wall and require different kinds of contextual information—for example, cues to promote awareness of agency for participants in both realms.

The Podium gives strong cues to its use as a presentation tool. However, its presence in an interactive cross-reality environment suggests opportunities to apply its basic affordances in new ways. For example, it lets users control document selection and arrangement in both spaces and thus could serve as a common centralized controller or as a tool to interact with specific subsets of physical or virtual displays. Virtuality can help promote fluidity; in these alternative use cases, the Podium likely wouldn't be represented as a podium in the virtual world, if it's represented at all.

Physical space is imbued with meaning and social affordance via architectural design.

Technology needs a social voice. During active collaboration in a physical room, the presence and activity of others in a connected virtual room must be made evident. One way to achieve this is by extending the collaboration vocabulary designed for the physical inSpace room into the virtual team room. For example, avatars of virtual participants who are uploading documents for sharing might be displayed with a halo of colored dots, in correspondence with how the inSpace Table advertises the same action for participants in the inSpace environment. In addition, the virtual-world participants might need some indication that artifacts in the physical room are being reconfigured. We've outfitted the inSpace environment with RFID carpet tile in anticipation of this. It's interesting that certain physical-virtual mappings might require pervasive, low-level sensing, whereas our physical-digital codesign efforts don't.

Because the Podium is in the assemble region of the inSpace environment, it 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 the physical or virtual team room to advertise intent in both realms at once. By tracking the Podium's position and orientation in the physical room, we can 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.

We designed the inSpace environment according to the philosophy that physical spaces and the digital services in those spaces should reflect the primacy of

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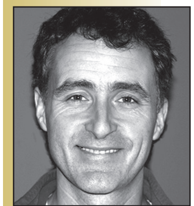

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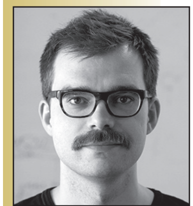

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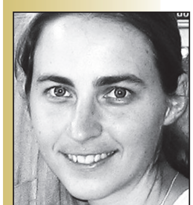

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human activity. By employing codesign in support of several distinct patterns of collaborative work, inSpace presents an approach to design that transcends traditional boundaries between built environments and digital services. Virtual worlds are, in some sense, the ultimate example of fusing space, artifacts, and digital services, and we anticipate that a similar emphasis on codesign will be beneficial for designers creating purely virtual collaborative environments. Another promising avenue for research lies in the application of this design approach when connecting physical and virtual environments for collaboration. Whereas mixed virtual and physical collaboration is undoubtedly different from that of purely physical, colocated collaboration, it too should reflect the primacy of human activity. As a result, we believe that the guidelines we identified in the first phase of the inSpace project for physical-digital codesign can help guide physical-virtual codesign as well. In our current work, we're building an infrastructure that promotes fluidity in how physical and virtual spaces are connected, gives a social voice to devices and services in both realms, and allows the codesign of physical and virtual spaces to support specific social practices. 🅿

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