Weightless Walls and the Future Office

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ABSTRACT
In this paper we describe how future office environments can benefit from the addition of *weightless walls*—virtual, sound blocking walls created using headsets. We particularly focus on exploring how different interaction techniques can be employed to efficiently create, erase, or edit the layouts of these walls, and envisioning how they could impact the overall office experience. Metaphorically, the end effect of integrating weightless walls into offices is that space will be treated in a way similar to how random access memory is treated in PCs; as a shared resource open to dynamic allocations, and whose usage is periodically optimized in real time according to the collective activities of the occupants. Furthermore, we view weightless walls as harbingers of the emergence of *synthetic space*—the eventual fusion of the architectural environment with the distinctive properties of digital bits.

Author Keywords
Weightless wall, active noise control, smart furniture, office design, synthetic space.

ACM Classification Keywords
H.5.2 Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Human Factors

INTRODUCTION
Due to advances in mobile computing and wireless communication technology, office workers nowadays enjoy a degree of mobility that was unthinkable only a decade ago. Designs of office environments have tried to keep pace with this shift, increasingly doing away with rigidly divided rooms in favor of more fluid layouts, characterized by the blurring of partitions and greater use of multipurpose spaces [19]. The intent is to enable workers to seamlessly transition between different tasks, making the most of new mobile technology. Such modern offices can be regarded as the latest variety in open-plan offices [27], which are known to possess advantages (in addition to being technology-friendly) such as the ability to foster communication among workers [3], improving performance for certain tasks [9], and (perhaps most importantly) needing lower costs for construction and maintenance. However, they are also criticized from time to time, as distracting workers from jobs [6], diminishing privacy [28], and having generally negative effects on the mental [12] (and sometimes also physical [22]) well-being of workers. Since these shortcomings all stem from the lack of partitions in the open-plan office, which also is the source of its benefits, solving them is not something that can easily be achieved through creative layouts of furniture.

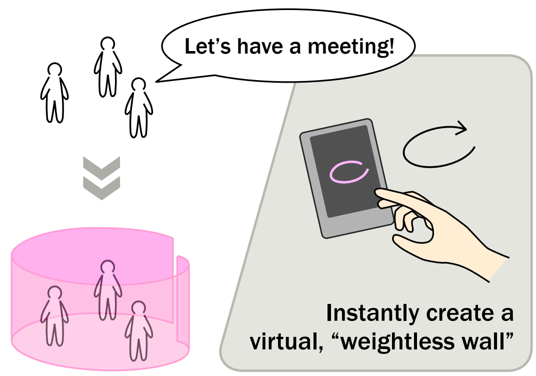

Figure 1. Weightless walls concept sketch.

In this paper we describe how the introduction of *weightless walls*—invisible, sound blocking walls created using custom headsets—may prove to be the solution that effectively marries the vibrancy and flexibility of the open-plan offices, with the quietness and comfort of the more traditional workspaces. With weightless walls, workers can easily tailor office spaces to best suit their tasks at hand.

The paper will proceed as follows. First, we will give a basic description of how weightless walls are technically realized, and explain its most rudimentary setup, with a simple touchscreen interface to manipulate the walls. User scenarios will be given to show how the system may be used in actual office settings. Next, we will describe two alternative implementations with more advanced interaction techniques, discussing how they could further transform the workplace experience. Throughout the paper, we will report the feedbacks and comments received from our colleagues, whom we had asked to try out the various aspects of our early implementations. The

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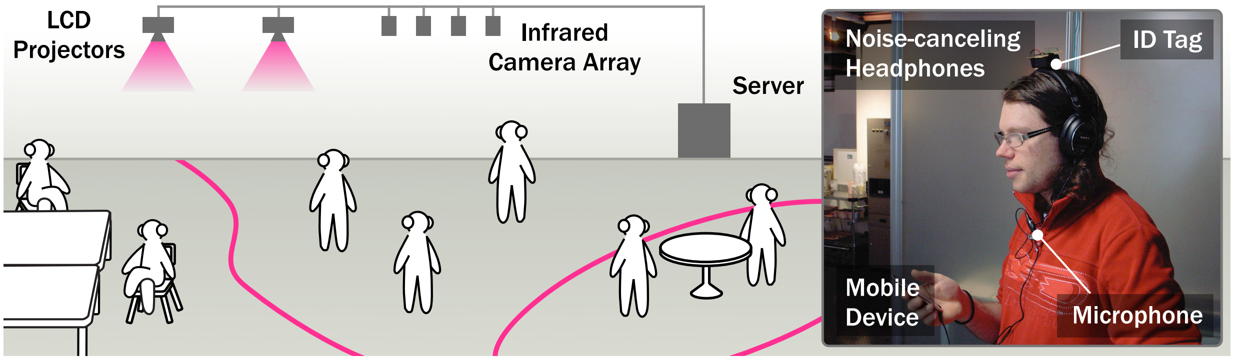

Figure 2. Weightless walls basic setup (left), headset (right).

paper will conclude by discussing the possible extensions to the technology, and its future implications, presented as the concept of "synthetic space".

"WEIGHTLESS WALLS"

Figure 2 shows the basic setup for creating weightless walls. Each user wears a headset, which consists of a pair of noise-canceling headphones and a microphone, both connected to a mobile device. In our current implementation we are using the Apple iPod touch as the mobile device, but most devices capable of WiFi communication could be used (the primary job of the device is sending and receiving audio data over the local network). Unique ID tags made with infrared LEDs are attached to the top of the headphones, which are captured by the array of infrared cameras installed on the ceiling. This allows the system to constantly monitor the location and head orientation of each user in the office.

The server continuously receives real-time microphone input from all users' headsets (via the iPods), and feeds the data to a line of 3D mixers, which mix the audio while maintaining 3D-space faithfulness of user conversations, by utilizing the user location/head orientation information obtained through the camera array. Outputs of 3D mixers are then sent back to each user's headset (again via the iPods). As a result of this procedure, spatial relationships between users are accurately reflected in the audio that each user hears; voice coming in from a person in the left side of a user will actually sound as it came from the left. Since audio is only transmitted within the local network, data compression is unnecessary, making the sound quality much superior to common VOIP software (e.g., Skype) and the latency minimal. The noise-canceling headphones cancel out (or at least dampen) most sound that is not produced by the system, and thus all communications between users will basically be headset-mediated.

This process enables users to engage in reasonably "natural-sounding" conversations, albeit through headsets (Figure 3). Given this configuration, simulating weightless walls can be done inside the server by artificially tweaking the mixer outputs in ways that would be plausible if the walls actually did exist. In our current implementation, volumes of voices that came from users on opposite sides of a "wall" are diminished

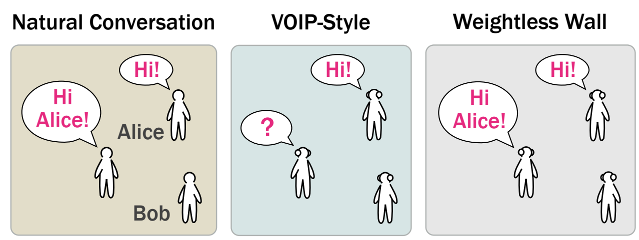

Figure 3. Headset-mediated communication. In VOIP-style communication, spatial information is lost and the user cannot tell which direction the voice came from.

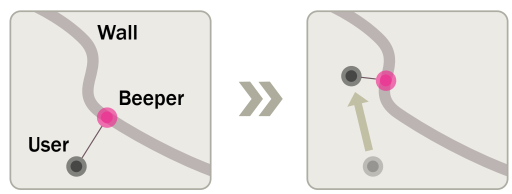

Figure 4. Beeper feedback. The beeper is placed along the wall, at the position with the shortest distance from the user.

by 90%. Better results may be obtained by incorporating advanced models of sound propagation.

Walls are made visible to users by casting them onto the floor using LCD projectors, but since they offer no tangible feedback when users bump into or pass through them, we provide awareness through an alternative means of using "beepers": virtual sound players that emit subdued, soft beeping sounds synthesized from sounds of woodwind instruments. When a user moves to within a certain distance from a wall, a beeper is "planted" along the wall at the position closest to the user (Figure 4). This enables the user to become aware not only of the wall's existence, but also of its approximate direction. The position of the beeper is dynamically altered in relation to changes in the user's location.

Our setup may strike some as being too obtrusive, due to the fact that users are required to wear headsets at all times while using the system. However, it should be noted that headsets are not inherently obtrusive; already models are on sale that weigh as little as five grams, and with Bluetooth eliminating any need of cords, we believe that some of the latest headsets are already no more obtrusive than eyeglasses. High-quality noise-canceling still requires bulky headphones (which may explain our current setup), but in time it should become possible to fit all the functionalities required for our system into a package as small as the state-of-the-art Bluetooth headsets, or even smaller, into sizes close to those of hearing aids.

Touch-Screen Interaction

As the most basic technique for manipulating the weightless walls, we have created a small application for the iPod touch that enables users to literally "draw" walls through a touch-screen interface (Figure 5). Since the application runs on the same iPod connected to the user's headset, under the current setup this method of interaction should be highly convenient for users. However, it should be noted that this convenience will evaporate if the headsets become capable of WiFi communications on their own (as we expect them to in the near future), negating the need of any external device.

The straightforward nature of touch-screen interaction makes it easy even for first-time users to design walls with complex layouts. However, since each user can individually alter wall layouts on his/her own device, there is the possible drawback that users would be able to attempt mutually conflicting operations (e.g., attempting to delete an existing wall while another user is editing its contour), which could be a cause of annoyance or confusion among users.

We have deployed the setup we described so far inside a single, middle-sized room within our research lab, and invited colleagues to try out the system in an informal manner. One issue we immediately noticed was that users tend to speak in much louder voices when using the system, similar to when listening to music on headphones. We believe that this is due to the headphones muffling the users' own voices, and could be alleviated by tuning the settings of the 3D mixers, so each user would hear more of his/her own voice. In spite of such issues users seemed to have had no serious trouble in having conversations over the headsets (they could play simple card games with no visible difficulty). However, the user experience was apparently still far from natural, and we received complaints about the "hissing" background noise (inevitable in current noise-canceling headphones) and that the original voices of the users are not completely canceled out, creating a faint echo-like effect. These problems derive from current limitations of noise cancellation technologies, and we expect them to be solved (at least to some extent) in the near future with further advances in the field. It should be noted that the headphones used in our implementation (Sony MDR–NC60) had an on/off switch for noise-canceling, and switching it on and off clearly revealed that the headphones *do* effectively suppress human voices, albeit not perfectly.

The touch-screen interface proved easy to use as we had expected, but users initially seemed to have difficulty grasping the geometrical relations between the screen dimensions and

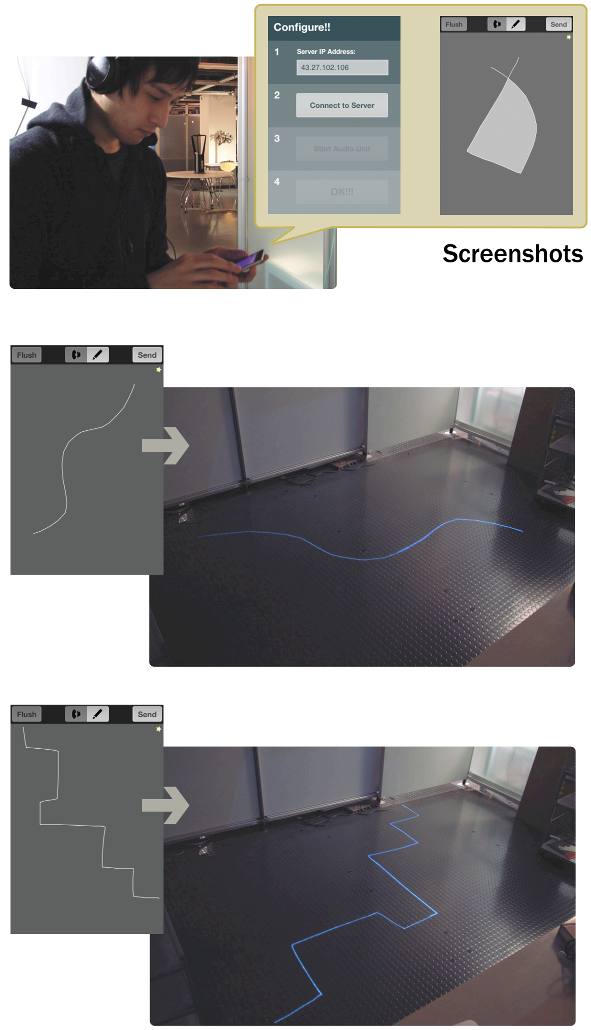

Figure 5. Touch-screen interaction.

the floor, most likely due to the solid gray background of the application GUI (as can be seen in Figure 5). This may easily be solved by replacing the single-colored background with a bird's-eye view of the office floor. We could not observe any actual instances of conflicting operations by multiple users, due to the small scale and the casual style of the trials. Overall the interface worked quite nicely, but observing the users we got an odd feeling that it might be working *too* nicely—changing the wall layouts seemed to us as requiring disproportionately little effort, considering that even minor adjustments to the architectural layout could have profound effects on the workers' behaviors and their social interactions.

USER SCENARIOS

With the addition of weightless walls, office spaces can start possessing attributes of both physical architecture and digital data, opening themselves to frequent alterations by workers. The level of flexibility promised in such environments would easily outshine even the most radical examples of open-plan office designs. Below, we will illustrate several new patterns of worker behavior that may arise in such future offices.

Meeting in a Noisy Room

Several workers in a large office room decide to have a short, casual meeting, to talk about their next business plans. However the room is rather noisy, due to another group of workers already engaged in a lively debate at the other end of the same room. The workers, after briefly considering the option of going out of the building to a nearby coffee shop, decides instead to just "draw" a weightless wall around themselves, immediately becoming isolated from the noisy surrounding environment (Figure 6). This scenario most clearly demonstrates our intended primary usage of weightless walls; as a temporary barrier that insulates workers from the familiar audial distractions of the office environment, such as chatter, footsteps, typing noise, etc.

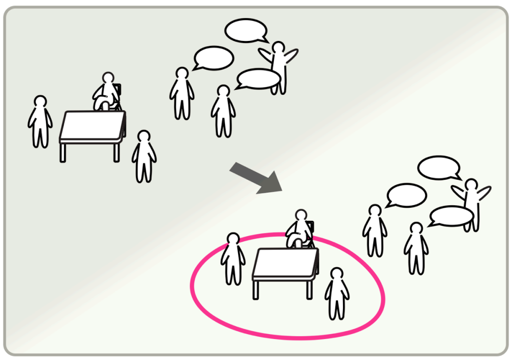

Figure 6. Meeting in a noisy room.

Presentation at the Hallway

A worker runs into a colleague at the hallway. The colleague works in a different department as the worker, but they had previously worked together in a collaborative project several years ago which had turned out to be a huge success. Asked by the colleague if there are any good ideas for new projects on which they can work together again, the worker "draws" a weightless wall around themselves, and starts a presentation using a laptop (Figure 7). This scenario shows how weightless walls enable workers to make the most out of mobile (or ubiquitous) technologies—the swift task-switching, characteristic of the mobile work style (evident in the quick transition to a laptop presentation) is amplified by the architectural support it receives from the weightless walls.

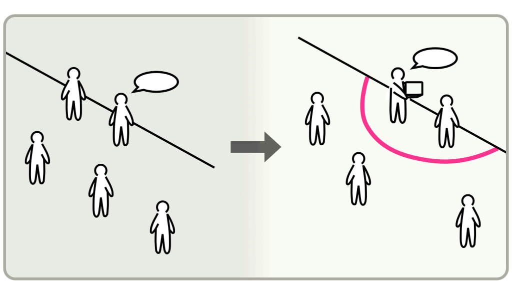

Figure 7. Presentation at the hallway.

Room Size Adaptation

A large room is already divided into two parts, with a weightless wall running through the middle. The two parts are both being used to hold brainstorming sessions, separately by two different groups of workers. Several workers on one side of the wall leave the room to attend another meeting at the next-door building, while on the other side several workers newly arrive to join the session. Workers on both sides of the wall agree to redefine the contour of the weightless wall, to better accommodate to the recent changes in the number of workers (Figure 8). This scenario illustrates the use of weightless walls not as a short-term fix as in the previous two scenarios, but as a permanent constituent of the office space. Note that such long-term usage of weightless walls naturally demands a higher standard of user experience, i.e., better sound quality, comfortable headset design, etc.

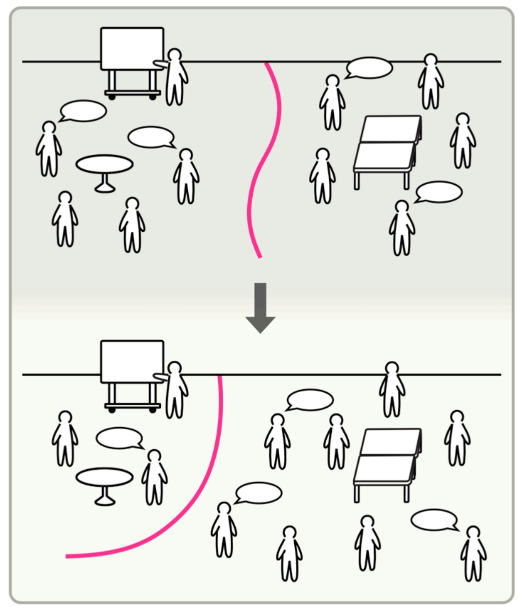

Figure 8. Room size adaptation.

These three scenarios demonstrate how weightless walls can allow more fluid use of offices spaces, giving workers the authority to freely reconfigure the workspace to fit their current needs. Offices augmented with weightless walls can take any state within the spectrum of office designs, from the relative tranquility of traditional workplaces to the frenetic openness of the modern designs. However, the scenarios also illustrate the limitations of the technology; effective use of weightless walls is restricted to suppressing audial distractions, and they are utterly powerless in blocking visual distractions or securing the privacy of workers, both functions easily fulfilled by traditional, physical walls.

Furthermore, even if we take an optimistic view concerning possible future advances in noise cancellation technology, it is not clear whether we could ever reach a point where users will perceive conversations over the headsets to be perfectly "natural". This is because our current setup is fundamentally unable to transmit any sound other than users' voices, which means the system can never provide a 100% accurate replication of the actual soundscape. Studies in workspace awareness [11, 14] have shown that non-speech sounds in offices (e.g., footsteps) can actually have positive effects on productivity, and the failure to communicate such sounds may well mean that the usage of weightless walls will be relegated to short-term uses as depicted in the first two scenarios.

Of course, it is also possible to envision a more brighter future for weightless walls where all three of the user scenarios become common sights in offices, and where lively crowds of workers (each with a tiny headset on their ears) constantly shape and mold the workspace (possibly a large, open space with minimal furniture) to better suit the tasks at hand. Such vision may seem far-fetched to some, but in fact a vision of a future society where people always wear high-tech headsets is one that has been put forward by other HCI researchers as well [29]. In the future, both our cell phones and our laptops may be replaced by advanced headsets, in effect creating the necessary platform for broad acceptance of weightless walls. At any rate, since the introduction of weightless walls would constitute a truly radical change in the makeup of the office environment, exactly how it will work out in actual practice is something that could only be found out through an extensive series of long-term studies.

ADVANCED INTERACTION SCHEMES

So far, we have described the most basic implementation of weightless walls, and discussed its possible use scenarios in actual office environments. However, a large part of the user experience of the system depends on the method provided to users for creating, erasing, and editing the walls. In addition to the touch-screen interface, we have designed two alternative interaction techniques that allow users to manipulate the walls in different ways. Below, we will explain the details of each of these techniques, and explore their potential impact on the workplace experience.

Tangible "Stones"

Tangible User Interfaces [13, 15] are interfaces where direct manipulations of physical objects are used to control digital information. Interaction using tangible interfaces tends to be more closely aligned with real-world logic compared to GUI controls, and hence is generally more easy to understand and intuitive from users' viewpoints. A common implementation involves physical objects that are moved around on a tabletop as user input, and an LCD projector that directly overlays the output onto the physical objects [30]. Here, the physical objects serve as both the input and the output of the system (which are so often disconnected in computer systems), allowing users to construct clear *mental models* of the system's internal workings [20]. Since our basic setup for weightless walls already includes LCD projectors installed on ceilings, we could build an office-sized variation of tabletop tangible interfaces by designing physical markers ("stones") that can be moved around on the office floor as user input (Figure 9). The strengths of tabletop tangible interfaces (the integrated input/output and the intuitive controls) should directly carry over to this interface as well.

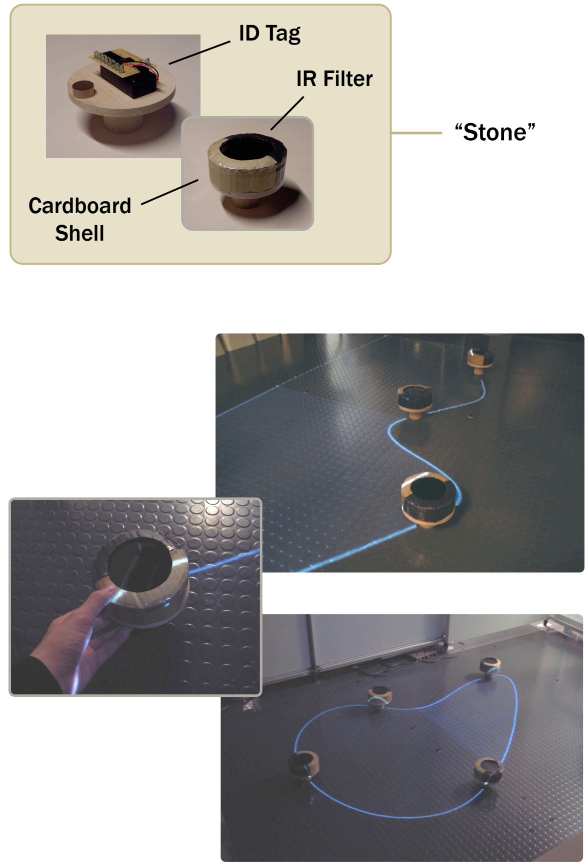

Figure 9. Tangible "stones".

We designed the stones as mushroom-shaped blocks to allow easy handling by users, and painted them using two different shades of color to make their orientations explicit. An ID tag made with infrared LEDs is embedded in each stone (similar to those on the headsets), to enable its position, orientation, and ID number to be tracked by the system. Two alternative stone designs (*go*-stone shape, and "kickable" stump) were also considered, but ultimately abandoned as they demanded greater efforts to move with precision.

Walls are defined as Bezier curves, where locations of control points are resolved from the positions and orientations of the tangible stones. The state of a single stone determines the locations of three control points: one as equal to the position of the stone, and the other two at a fixed distance from the first, in mutually opposite directions (Figure 10). The stones are connected in the order of their IDs, and for the two stones with the smallest and largest IDs (*end stones*), straight-line rays are drawn from their centers. In cases where these two rays intersect, they are instead replaced with another Bezier curve that connects the end stones, creating a closed wall. Defining the walls as Bezier curves as opposed to straight lines allows users to build walls with complex contours, using only a limited number of stones.

In addition to integrated I/O, using the tangible stones should have advantages such as eliminating any possibility of users

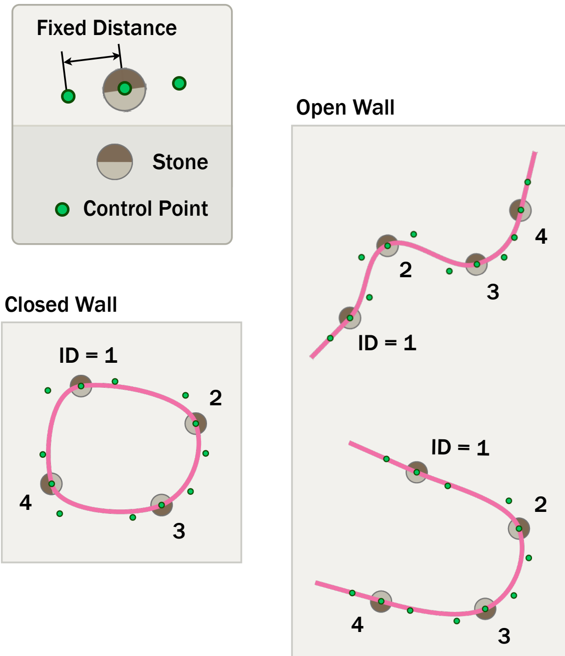

Figure 10. Defining walls from stone states (Note the orientations of the stones, indicated by color shades).

performing mutually conflicting operations (which had been a concern with touch-screen UI), and giving a real, physical representation to the walls which could make them easier to notice (and perhaps also more "believable"). Possible drawbacks include the need to physically move the stones to edit wall layouts (which seems at odds with the name *weightless walls*), and the sheer awkwardness of having multiple stones spread out on the office floor.

Again, we invited colleagues to casually try out the "stones" interface, in the same middle-sized room within our research lab. In general, users seemed to be able to grasp the logic of the interface with little practice, but the criteria for connecting the end stones were perhaps a little unduly complicated, and appeared to have caused confusion in a couple of cases. In comparison to the touch-screen interface the difference in the style of interaction was clear from the start; when using the stones interface, users generally kept low positions in the middle sections of the room (which is obviously borne out of necessity, since the stones require users to crouch and move them with their hands one by one), whereas with the touch-screen interface they chose to stand on the edge of the room, so as to take a good view of the whole space.

Due to this difference in the style of interaction, the tangible stone interface and the touch-screen UI are likely to be effective in different types of office environments. The tangible interface (with its hands-on style of interaction) is perfect for making small, frequent revisions of wall layouts, but would be totally inefficient for creating large-scale walls. Also, the need to place a number of large physical markers on the floor makes it unsuitable for crowded rooms with many furniture. Considering these traits, one appropriate use of the interface would be to divide a meeting room into several smaller parts, as in the third user scenario we described in the previous section. The tangible qualities of the stones are ideal for making series of adjustments in a collaborative manner (as depicted in the scenario), and since here the wall is a permanent component of the meeting room, most changes to its layout will likely be minor in scale. The touch-screen interface, on the other hand, should work better for large workspaces with occasional needs for complete overhauls of wall layouts. Here, the ability of the interface to design the walls in a top-down manner, from an overall plan or image of the desired layout, would prove to be highly beneficial.

Dynamic Optimization

Both the touch-screen UI and the stones interface, while taking different approaches, were consistent in their reliance on manual manipulations by users. However, the digital properties of weightless walls should also make them open to automatic manipulations, where optimal wall layouts are calculated in real time, based on the collective activities of occupants. This will have the important consequence of realizing dynamic allocation of architectural resources—pieces of office space will be dynamically assigned to workers, in a way equivalent to how operating systems allocate memory to different applications. Below, we will describe a technique that offers the approximate experience (a close-enough pastiche, if not *the* real thing) of such dynamic optimizations.

A pivotal component for automatic wall optimizations would be a dependable method for recognizing the activities of each worker. Such problem of activity detection has been a rigorously studied topic in the field of Context-Aware Computing [10, 26], but nonetheless still remains difficult, particularly for environments like offices where a range of diverse activities can take place with little differences in outward movements. In our technique, we have attempted to devise a novel solution to this problem by focusing on the relationships between worker activity and office furniture.

Our technique is founded on one simple observation: the arrangement of furniture, especially chairs, can serve as fairly trustworthy indicators of several aspects of worker activities. For example, if a group of chairs are positioned in the shape of a circle with all of them facing toward the center, it seems plausible to assume that workers are currently having a conversation or a meeting using the chairs (Figure 11). Similar

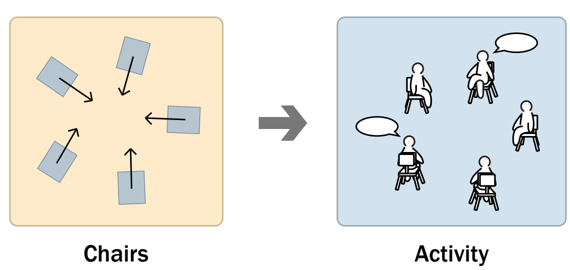

Figure 11. A plausible relationship between the arrangement of chairs and worker activity state.

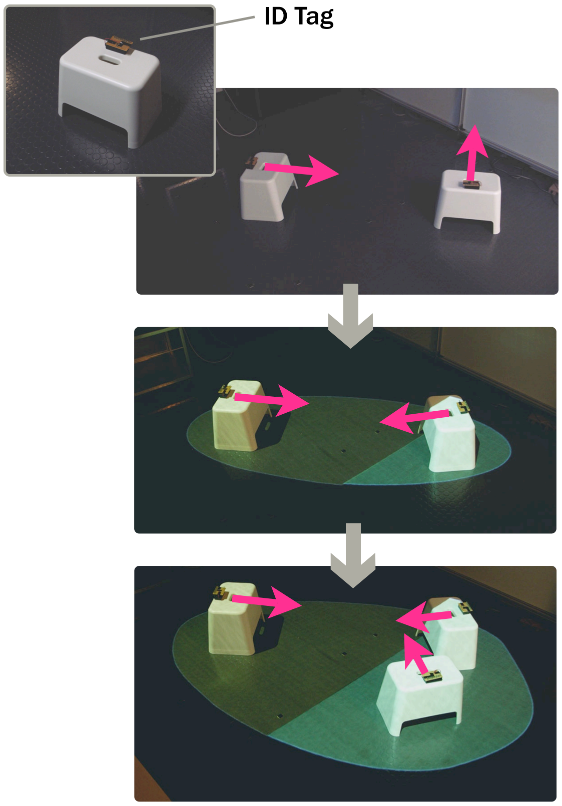

Figure 12. Semi-automatic layout optimization using "smart" chairs (Pink arrows indicate chair orientations).

observations can be made, of course, by referring only to the locations and head orientations of the workers (as in [8]), but in that case we will need to tolerate a much higher degree of second-by-second fluctuations in the observation results. In our system that would directly translate to fluctuating, erratic wall layouts (which is impermissible), and therefore the use of furniture would be much more desirable.

Based on the above observation we attached infrared ID tags to plastic stools, making a set of "smart" chairs whose positions and orientations can be tracked using the camera array (just as the headsets and the tangible stones). When multiple chairs are placed nearby facing each other, a bubble-shaped wall is created to enclose the chairs (Figure 12). The idea is that, by designing the rules for forming walls in ways consistent with how workers naturally arrange chairs when having conversations, we may be able to make the workers cease to be aware that they are actually performing the manipulations themselves. If we are successful, the user experience should closely resemble that of a fully automatic, wall-layout optimization technique (if such a thing existed).

Also, when multiple bubbles overlap each other, the contour of each bubble shrinks to eliminate the overlaps (Figure 13). Therefore, as the workplace becomes more crowded (in turn making space more scarce) the area of space alloted to each bubble, and hence to each group of workers, is reduced accordingly. This amounts to a crude implementation of RAM-

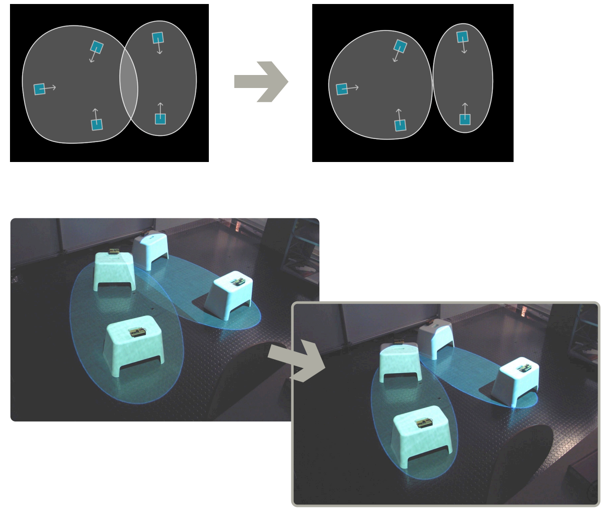

Figure 13. Eliminating overlaps.

style allocation of architectural space, allowing efficient use of office space with constant, real-time optimizations.

Our current implementation involves only chairs, but the basic idea can be extended to include a family of "smart" furniture. For example we could design a "smart" table, which may have the ability to enclose all the chairs located nearby inside a huge bubble of weightless wall (thus, chairs placed across a "smart" table will always belong to the same bubble, regardless of their orientations). Making furniture "smart" is simply a matter of attaching an ID tag and defining a rule of how it should influence wall layouts.

We have implemented this technique and invited colleagues to try it out, again in the same middle-sized room within our lab. However, since the advantages of dynamic optimization is something that (by design) would only become evidenced under actual work situations (which our mid-sized room and the casual style of the trials forbade us from replicating faithfully), we were unable to gain much in terms of meaningful observations. However, we did receive one interesting comment from a user, that the interaction would feel more "right" if the walls were formed *gradually* after the chairs were arranged, not immediately as in our implementation. Although it may be inappropriate to try to draw conclusions from such a vague comment, we have the feeling that this may in fact be related to the impression we got (described earlier) testing the touch-screen UI—that drawing walls on a touch-screen feels "too easy". It may be that, since we are ingrained with the notion that walls are objects of considerable mass, there is a kind of shock when they appear suddenly out of thin air, even if they are in fact virtual, *weightless walls*. Making the walls appear gradually, as the user had commented, may be a good way to reconcile the interface with our longstanding conception of walls.

Though our current achievements only constitute a small initial step, the concept of a dynamically configuring workspace is extremely promising. In the modern workspace, it is common to see workers struggling for space in a crowded room, when the room next door is, in fact, unoccupied. Such inefficiencies have negative effects not only on productivity, but apparently also on the environment, as can be seen in reports that show buildings to be one of the leading sources of CO_2 emissions in the developed world [1]. If self-configuring offices could be shown to effectively curb emissions, it would give us another strong motivation for continued development of this technology. (Although we have to add that our current setup is probably resulting in even higher emissions, due to the large number of electronic devices involved.)

EXTENSION IDEAS

As we have explained, the current implementation of weightless walls still has many shortcomings, creating a rather large discrepancy between the visions promised and what is actually offered. In this section we describe some possible technical enhancements to the system, that may resolve the limitations or add to its strengths.

One fundamental problem with our current setup is that conversations over the headsets cut off any non-speech sounds, deleting a potentially important source of workspace awareness. A possible solution to this problem is to embed microphones in various surfaces within the office (floor, tabletop, etc.), allowing workers to hear some ambient sound in addition to other users' voices. Laying out microphones in dense square grids would make it possible to estimate the approximate location of sound origin through triangulation, so that captured sounds can be integrated into the system in spatially faithful ways, just like workers' speech. The result will be a more complete, truthful replication of the office soundscape, that includes footsteps, typing noise, and various other non-speech sounds commonly heard in the workplace.

Another possible extension would be to give a 3-D presence to the weightless walls, making them closer to real, physical walls. Straightforward ideas for this would include incorporating "hanging walls" that freely move along rails attached to ceilings, or introducing systems that can create projection screens in mid-air, like FogScreen [24]. However, such configurations are often expensive and need far-reaching modifications to the underlying office building, and are unrealistic from economic viewpoints. An alternative solution would be to replace headsets with HMDs (Head-Mounted Displays), so that users can "see" the walls in 3-D, seamlessly overlaid onto the office architecture. HMDs have long been known to be rather large, awkward devices, but their form factors have been refined to the point that some recent models are already no larger than ordinary sunglasses.

"SYNTHETIC SPACE"

We are positioning our work on weightless walls as part of a larger-scale initiative, aimed at realizing "synthetic space"—the architectural space of the future, where every comprising element (e.g., walls, windows, etc.) is superseded by highly malleable, digitally controllable counterparts. For occupants of synthetic space, reshaping the built environment is something that could be done with as little effort as changing the desktop background on a present-day PC (Figure 14). In effect, realizing synthetic space would be equivalent to achieving the *digitization of architecture*. This puts synthetic space within the long line of conventionally physical objects, that have been successfully digitized over the years (e.g., digital music, e-books, etc.).

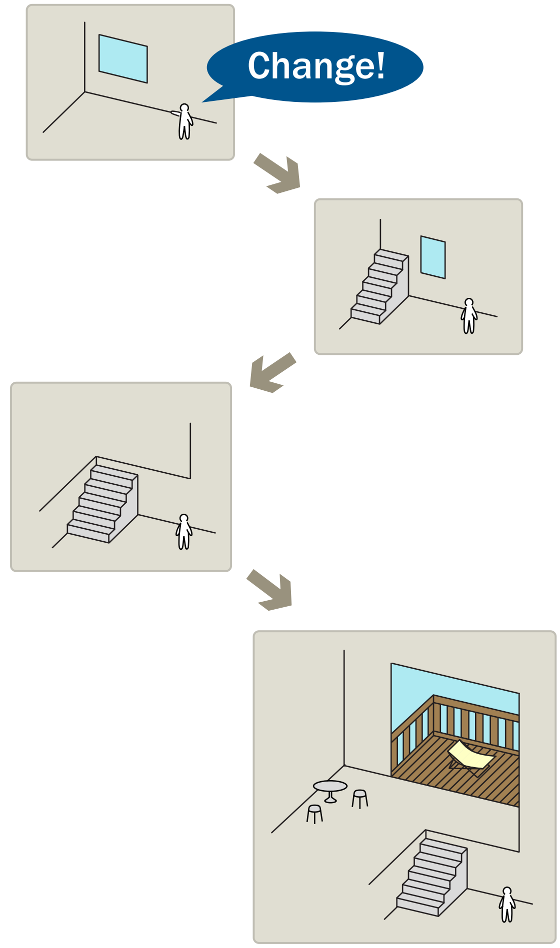

Figure 14. "Synthetic space".

Synthetic space would enable us to make more efficient uses of architectural resources, much more so than only incorporating weightless walls. The "synthetic" office of the future may consist of rooms with variable sizes and forms, that constantly shrink or expand according to what activity is taking place inside. A room with many workers having a lively discussion could be increased in size, at the expense of unused or scarcely occupied rooms. Such radical architecture would surely raise many interesting questions (e.g., What would be the role of architects?), offering a vast potential for new topics in HCI research.

Our work on weightless walls is intended to provide a partial window to the possibility and experience of synthetic space. We are also working on several other projects that attempt to tackle the theme from different angles, such as investigating how the concept of synthetic space may transform non-office environments (e.g., home, city streets).

RELATED WORK

Weightless walls rely on a combination of headphones and microphones to selectively pass through (and shut out) sound. This setup has been explored in many prior work, one of the earliest of which was Smart Headphones by Basu and Pentland [2]. Their system allowed users to hear people's voices (extracted and amplified using audio processing) even while listening to music at high volumes. Mueller and Karau [18] have built a system with similar hardware configuration, and designed an application where two people (both wearing the system) can have conversations regardless of the distance between them, by amplifying the voices of each other. Related attempts can also be found in the area of media art, of which a highly publicized example is Ambient Addition [31], a system that converts urban noise (e.g., traffic noise, construction noise) into electronic music in real time.

Danninger et al. [8] built on these approaches and explored how augmenting soundscapes can enhance communications in office environments, developing a system where head orientations are used to determine the interruptibility of workers, and conversations (through headsets) are allowed or disallowed based on the results. This work was further extended in [17], where cubicle walls made of switchable glass (which can be made either transparent/opaque) become transparent only when they are flanked from both sides by workers having conversations over the system. Although these attempts stop short of suggesting an altogether redesign of the workplace architecture, the intention to employ soundscape alteration as a means to introduce higher flexibility into the office environment is clearly in line with our work.

The key difference that separates our design from these prior works is our use of the "wall" metaphor, which gives users a comprehensible conceptual model to easily understand how the soundscape is (and can be) altered. In contrast, in earlier designs the office soundscape could be dramatically altered with just a flick of the head, leading perhaps to rather unpredictable and intractable user experiences. The wall metaphor adds a measure of intuitiveness and stability to the interaction, which in our view is the decisive factor that makes our work credible as a vision of the future office, not just an interesting technical demo. Also, since the walls are projected onto the floor users can have a shared understanding of how the soundscape is modified, which leads to the establishment of *common ground* [7], an important factor in CSCW (Computer Supported Collaborative Work) known to improve the efficiency of collaborations. Similar metaphors of imaginary walls have been used (although unrelated to soundscape alteration) to visualize functional boundaries in smart, sensor-embedded environments [16, 23], offering further testaments to the aptness of this metaphor.

An alternative method for customizing the office soundscape is using masking noise [21] instead of active noise canceling. This is already a feasible technology, widely deployed in actual workplace environments. However, since masking noise does not discriminate between voices of different people, the technology is incapable of providing the level of soundscape fine-tuning offered by weightless walls.

Regarding the designs of future office environments, a number of provocative and influential visions have been put forward over the years [5, 25] in the context of HCI and CSCW. However, the majority of these visions has been concerned with the problem of *connecting* distant spaces by using video monitors and/or sophisticated projection techniques, and few have focused on the problem of *dividing* spaces which is the primary concern of weightless walls. We believe that maybe two or three decades from now, the actual offices of the future will be supporting both the connection *and* the division of space with little restrictions, realizing an experience close to our notion of *synthetic space*.

CONCLUSION AND FUTURE WORK

In this paper, we described how future office environments can benefit from the addition of *weightless walls*—simulated walls capable of obstructing sound. We have described three different interaction techniques for manipulating the wall layouts (touch-screen interaction, tangible stones, dynamic optimization), which should contribute to making the technology applicable to a wide range of office environments, serving diverse professions/activities. Further improvements can be expected regarding the user experience in the future, with advances in noise cancellation technology and developments of smaller, more comfortable headsets.

We are planning to conduct a formal user study of weightless walls; already, we have done some informal studies involving nine of our colleagues (the findings from which we have presented in this paper), but since those studies were done in a casual manner not closely mirroring actual work situations, we still have many unanswered questions. In particular, we would like to know how well weightless walls, with their utter ineffectiveness in protecting worker privacy or blocking visual distractions (factors known to impact worker satisfactions [4]), would function as viable replacements for physical walls. Could they make traditional walls largely obsolete, turning the office of the future into one large, open space? Or would workers still feel a need for traditional walls, relegating weightless walls to stopgap uses? We hope to obtain the answers to these questions, through a long-term study where subjects will be asked to perform various actual office tasks, with and without using weightless walls.

We believe that the vision of "synthetic space" can become an important topic of investigation for Human-Computer Interaction in general, increasingly so as we move further into the 21st century. Innovations in mobile and ubiquitous computing has made computers constitute already a sizable share of the built environment, making large-scale transformations inevitable in our relationship with architectural space. Also, the heightened awareness of the society toward environmental issues is demanding new, radical ideas regarding building use. Although we currently do not know whether weightless walls (or synthetic space) would actually be able to translate to more environmentally-friendly ways of living, we believe that presenting bold alternatives to existing ways of thinking can make important contributions, at the very least by setting off further discussions.

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