Designing Mixed Reality

PERCEPTION, PROJECTS, AND PRACTICE

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Mixed Reality is an increasingly prevalent technology that merges digital simulations with physical objects or environments. This paper presents principles for the design of mixed reality compositions. The principles are illustrated by projects and experiments by the author involving architecture and robotics.

INTRODUCTION

Since completing my dissertation at the University of Plymouth, I have experimented with various technologies to test my thesis. The dissertation tried to answer a question arising from present technologies. If, as research suggests, simulation can compete with—or even supplant—their physical counterparts, what might its effect be on architecture? I found that such effects could apply to nearly any design field—namely, any that used representation (i.e. drawings, models, specifications) in generating a physical product (Anders 2004).

Such effects would not lead to complete virtualization. While an architecture of cyberspace may be possible, it can only be realized through the physical systems that sustain it. The virtual needs the material for its realization—even imaginary architecture requires the brain and body of the imaginer. Since our spatial imagination is a product and tool for cognition I proposed that the virtual and physical are co-dependent and, possibly, inextricable.

This paper proposes seven principles for designers who seek to integrate physical and virtual elements. These principles are illustrated by projects done over the past two years. These projects are not conclusive—each is still in development—however, even at their present stage they show the principles in action. Before proceeding, however, I should introduce some concepts used in this discussion.

MIXED REALITY

While we experience a form of mixed reality every day (virtual entertainments on physical screens, simulated voices on physical cell phones), *Mixed Reality* is a technology that reconciles and integrates virtual and physical worlds. The birth of Mixed Reality (MR) in 1962 coincided with that of Virtual Reality when Ivan Sutherland used transparent displays to place simulations into his lab space (Sutherland 1963). The term "Mixed Reality," however, had to wait until 1994 when Paul Milgram and Fumio Kishino described technologies "that involve the merging of real and virtual worlds somewhere along the virtuality continuum which connects completely real environments to completely virtual ones" (Milgram and Kishino 1994).

Along this continuum we find different blends of the physical and virtual (Figure 1). Toward the virtual end of the scale we find *Augmented Virtuality* in which physical elements are set into a virtual world. Its opposite, near the other end of the scale, is *Augmented Reality* (AR), which places virtual objects into actual settings. These technologies are distinguished from simple visual collage in that the virtual and physical elements of a scene are linked. Namely, if you move your point of view actual and virtual objects move in parallax, as though they were in the same space. Effectively, the virtual and physical are conjoined in Mixed Reality.

The technology depends on our ability to make coherent space from sensory information. Seen as a product of consciousness, this space situates the artifacts of sensory cognition—color, spatial relationships—and those of other processes like identification and memory. From this standpoint all objects, virtual, physical and imaginary, are potential occupants of psychosomatic space. And while we can distinguish their relative reality, virtual rocks cannot break physical windows; they cohabit quite comfortably in our day-to-day experience of the world.

Mixed Reality, especially Augmented Reality, has become increasingly popular in computer science circles because of its unique challenges. Not limited to visual display, AR can also incorporate sound, touch, and even smell, depending on the application involved. Several professional organizations such as ISMAR and special interest groups of IEEE specialize in AR, and hold regular conferences on its use. AR projects regularly feature in arts and technology conferences such as SIGGraph, ISEA, and Ars Electronica.

CYBRIDS

As mentioned, Augmented Reality places virtual objects into physical settings. This is what we usually see in typical AR projects, movie special effects, or in advertisements where the featured cars do miraculous things. However, despite the placement of a virtual element in

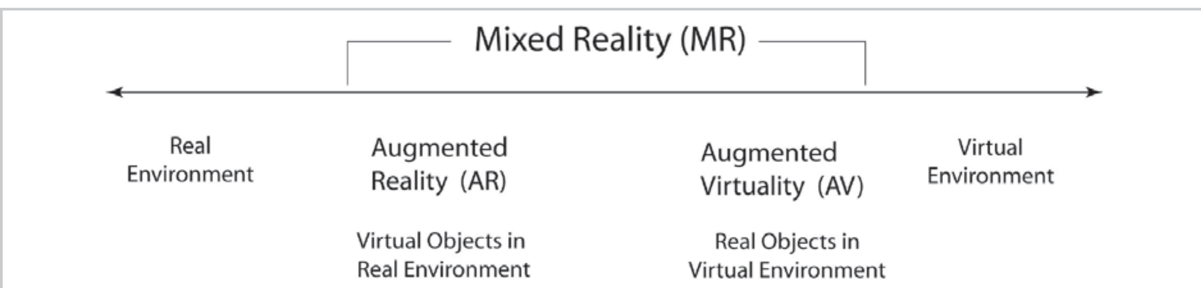
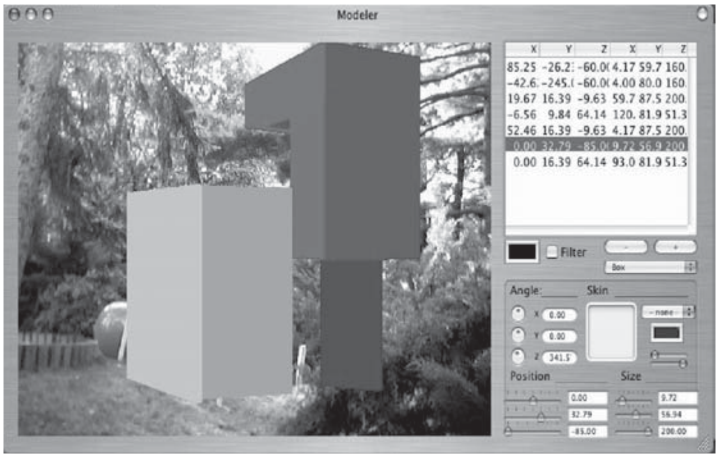
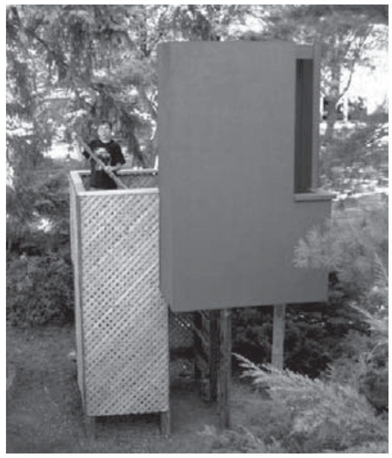


FIGURE 1 A representation of Milgram and Kishino's Virtuality Continuum





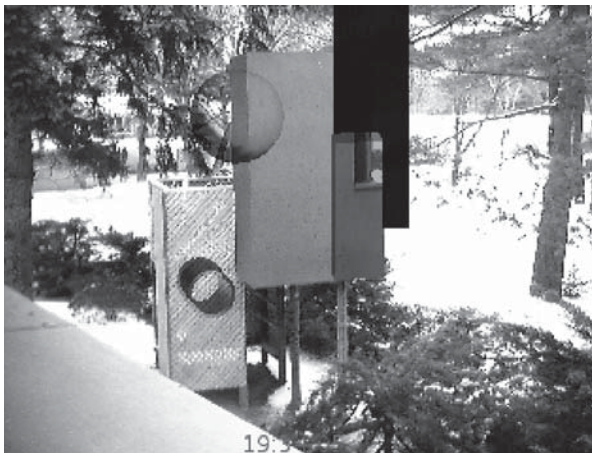


FIGURE 2 (above left) The Ambiviewer interface showing an early model of playhouse. The Mixed Reality model is situated on-site using GPS and a visual fiduciary feature: the red object on the lower left.

FIGURE 3 (above right) Playhouse as built from Ambiviewer model

FIGURE 4 (left) Playhouse with virtual objects attached. The resulting cybrid is seen through the Ambiviewer interface.

an actual scene, the two are distinct from one another. We rarely see the integration of virtual and physical objects within the same scene.

Somewhere between the extremes of Milgram and Kishino's Mixed Reality is a mid-point where integrated virtual/physical objects occupy a mixed reality space. These would incorporate the material presence of sensory objects with the capacities of virtual ones. Such hybrid objects, here called *cybrids*, would be the native occupants of Mixed Reality.

Examples of cybrids may be seen every day. For instance a television set could be called a form of cybrid. It incorporates both the hardware for display, as well as the virtual space of the television image (at least when turned on). The physical apparatus generates the virtual image but the two are not integrated—action in the screen space does not affect the television set. A TV car crash for instance will not knock the television off the shelf. But knocking the TV off the shelf would certainly affect the cars on the screen! A proper cybrid would allow seamless interaction between its virtual and material parts.

Computers would be better examples than TVs since their operating systems manage interaction between the computer's hardware and software. The icons and graphics of the user interface constitute a kind of virtual space native to the computer. If we click the right virtual item on the screen, we can turn the computer off. If we then click the physical power button, we can restore the virtual space of the screen and its icons. The physical and virtual support one another.

CYBRID PRINCIPLES

Cybrids and other Mixed Realities reflect the mixed reality of contemporary culture—a psychological and social blend of actuality and simulation. Accepting this we open onto a range of questions: How could we design for Mixed Reality? What would characterize cybrid designs, and how would they differ from other forms of design? In an effort to answer these questions, I have proposed seven principles for cybrid design (Anders 2005). I expand upon them here, illustrated with examples taken from my recent work.

1. COMPREHENSIVE SPACE: CYBRIDS EXIST IN A COMPREHENSIVE SPACE THAT COMPRISES THE MATERIAL, SYMBOLIC AND COGNITIVE ATTRIBUTES OF SPATIAL EXPERIENCE.

The idea of *comprehensive space* is particularly useful to designers of cybrids. It encourages development of projects free of bias toward either material or simulated solutions, offering instead the broad spectrum that lies between. As a mental frame for cybrid development it has useful entailments. For instance cybrids evolve from a space recognized as a product of consciousness. This space pre-exists any of the project's manifestations, surviving until the last memory of the project is lost.

This suggests that the *life* of the project extends from the earliest inclinations of its creators to well beyond its construction. The cybrid is an evolving entity rather than a final product; it embodies the information of its design, production, its use, transformation and eventual dissolution.

I have used this principle as the starting point for several projects, including an office space, a playhouse, and a small robot. In all cases the virtual and material were considered subsets of a cognitive, comprehensive space. Of these projects the playhouse comes closest to conventional architecture, i.e. a design document preceded construction. In this case I used Werner Lonsing's Mixed Reality software, *AmbiViewer*, to outline the design on the site. The house was built from this mixed reality "sketch" much as a normal project would be from working drawings. While I had anticipated using the house as a site for virtual exploration, the virtual components were designed and added later (Anders 2005) (Figures 2, 3, and 4).

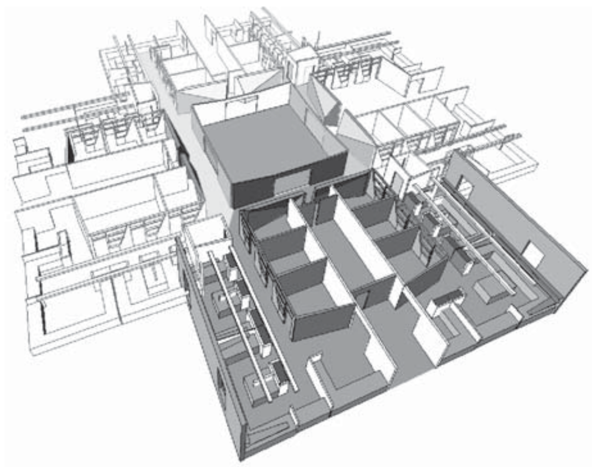
The virtual space was always part of the Caltech office space. Large, specially located mirrors reflect the offices beyond the confines of the building. This mirrored space is more than an optical illusion since the reflections are to be realized in cyberspace as a virtual annex that supports and *houses* the remote sales force and outlying services. This extension would be eventually viewed in on-line worlds such as Second Life (Figure 5).

A final example is a small robot I built recently to demonstrate the coupling of virtual and physical components. In this case the virtual and physical were considered simultaneously as parts of a composition. We will come back to the robot shortly.

2. COMPOSITION: CYBRIDS ARE MIXED-REALITY COMPOSITIONS THAT CONSIST OF MATERIAL AND SIMULATED ELEMENTS.

This principle concerns the integration of physical and virtual entities within a coherent design. A cybrid's composition may be observed in a variety of modes, through direct observation as well as by mediating technology. The design of the cybrid would determine the nature of constituent elements, as well as the type and number of techniques that would support it.

The office space and the robot were both designed with the virtual and physical components in mind. The playhouse was intended to be a test bed for mixed reality experiments. As such the cyberspace became an empty vessel to receive virtual elements. In this sense, the playhouse resembles aspects of my dissertation's proposal for the Planetary Collegium. There too the adjoining cyberspaces were to house virtual objects created after the project was realized (Figure 6).



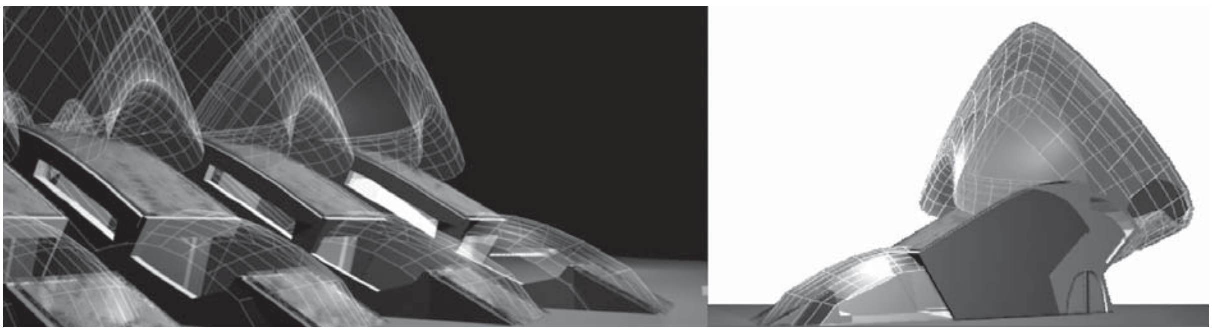


FIGURE 5 (top) The diagram above shows the cybrid layout of the Caltech offices. Only the lower right quadrant of the plan is physical. The remainer (shown faded) is virtual, being reflected both in the scheme's large mirrors and as a navigable space in a 3D-World. The on-line portion is in development as of this writing. The red square at center is a virtual conference room that will resemble the actual conference room in another part of the building.

FIGURE 6 Images from the dormitory portion of the Planetary Collegium project. On the left s a berm-structure consisting of individual dorm units, one of which is on the right. The gray volumes represent zones in which virtual objects may appear after construction. The volumes were developed at the same time as the actual living spaces.

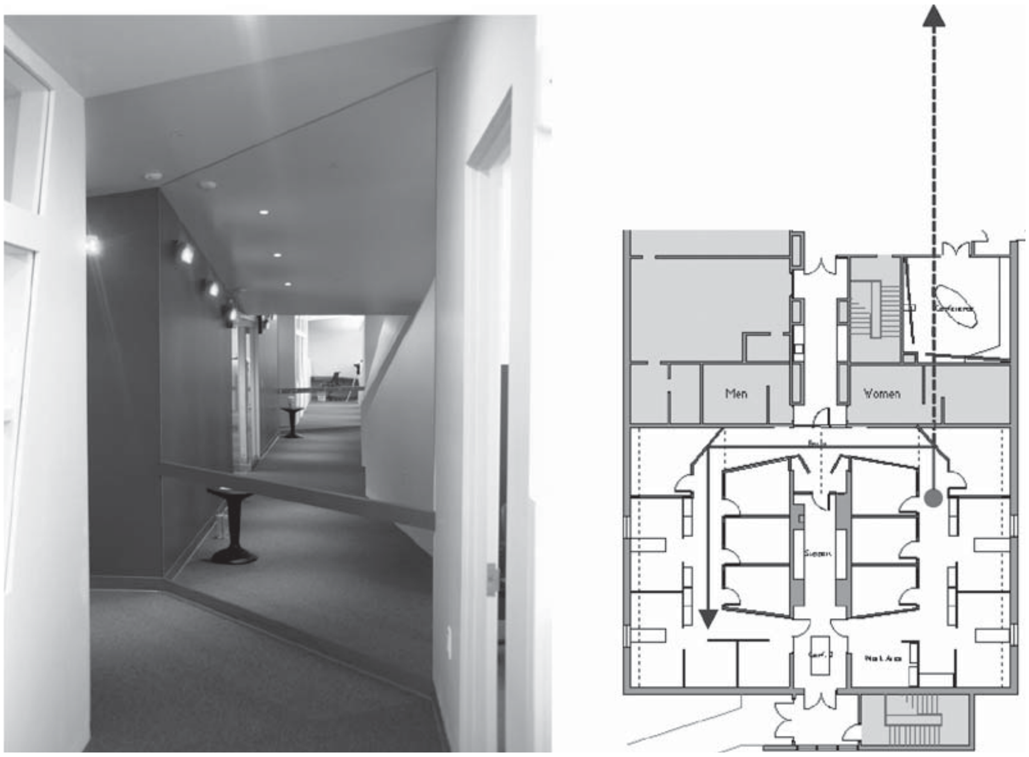


FIGURE 7 On left is a view through the entry of the office space. The key plan on the right shows the location of the camera (red dot), indicating the reflected light in the mirrors (blue line), and the illusion of a virtual space beyond. (dashed blue line) This virtual space is part of the overall cybrid space of the design. (See Figure 5)

3. CORROBORATION: CYBRIDS OFFER A RANGE OF EMPIRICAL MODES THAT CORROBORATE ONE ANOTHER.

We interact with our world through several senses at once. For example when I am chatting with a friend, the face of the friend appears to my eyes where my ears suggest it to be. The effect is crucial to my sense of being present in a space. This corroboration is a key element in cybrids as it leads to a unified effect for the observer. Corroboration can be achieved in part through composition, i.e. the physical configuration sculpturally suggests the virtual element, or by the orchestration of modes by which the cybrid is perceived. We can observe these modes directly through the senses or through their media equivalents. Corroboration distinguishes cybrids as compositions rather than mere aggregations of effects, a subject addressed in Principle 2.

The Caltech offices and the robot best demonstrate the corroboration principle. The mirrors of the office suggest the virtual space of the company, a space that will eventually be accessed through a three-dimensional on-line domain (Figure 7). Conversely, if you should visit this domain, you would enter the physical part of the office through the mirrors. In this way the mirrors play the role of windows or doors depending on whether the space is visited physically or on-line. The on-line experience is corroborated by what we see in the physical space, and vice versa.

The robot employs two ultrasonic sensors and an on-board processor. The sensors are effectively the eyes of the robot and, together with the processor, determine the distance to the walls and other objects (Figure 8). However, in this case, the sensors are used to define the virtual component of the cybrid, an invisible, roughly triangular blimp shape in front of the robot (Figure 9). The stereo-optic placement of the sensors lets the robot know whether the virtual object is being pushed, pulled, or nudged side-to-side. The physical robot responds as though the virtual element were a material part of the machine.

This response is confirmed by the use of a Mixed Reality software, ARToolkit, designed by Mark Billinghurst and Hirokazu Kato. Operating on a separate computer this software lets users see the invisible shape along with the robot. In this case corroboration of the virtual element occurs at a number of levels 1) that of the two sensors and processor together define the blimp; 2) the motion of the robot in response to “touching” the virtual object; and 3) the ability to see the blimp and robot using ARToolkit. Corroboration lets us assemble these impressions into a cybrid whole, the robot and its invisible object.

4. RECIPROCITY: RECIPROCITY BETWEEN A CYBRID'S PHYSICAL AND CYBERSPACES ALLOWS ACTIONS IN ONE DOMAIN TO AFFECT THE OTHER.

Reciprocity concerns the behavior of the composition—the integrity of the cybrid—rather than its supporting technology. An example of weak reciprocity would be the one-way correspondence between CAD files and the actual building they specify. This is a weak coupling because the relationship between them is barely reciprocal—if at all. Changing the CAD file doesn't affect the building or vice versa. The playhouse and office space are good examples of weak reciprocity since the virtual and physical components, to this point, do not interact beyond being parts composition.

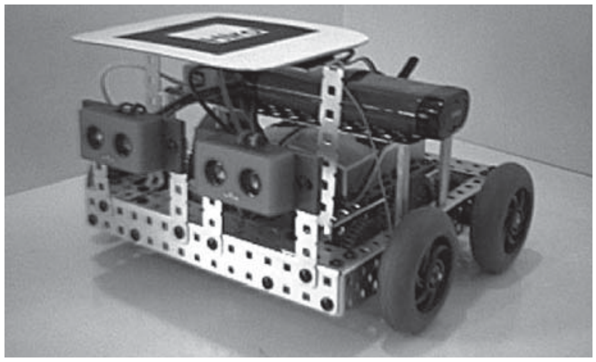
Strong reciprocity requires a tighter coupling between material and cyberspaces so that change in one state affects the other. Current examples would include monitoring/control systems, surveillance and building operation networks.

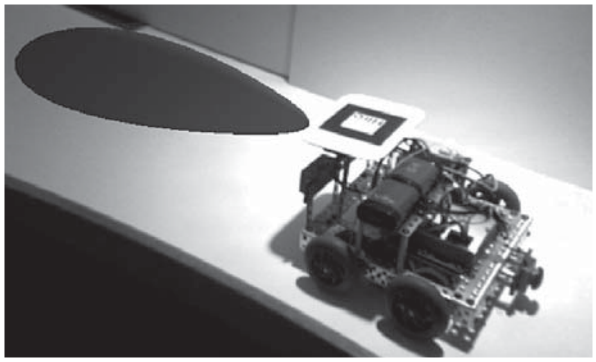
The images above show strong reciprocity between physical and virtual components (Figures 10 and 11). Actions on the virtual element affect the physical, i.e. "pushing" on the blimp causes the robot to move back. Conversely actions on the physical element, for example lifting or turning the robot, cause the blimp to move as though it were part of the machine.

5. EXTENSION: CYBRIDS PROVIDE USERS WITH A COHERENT SPATIAL ENVIRONMENT THAT EXTENDS THEIR AWARENESS BEYOND THE CONCRETE WORLD TO A DIMENSIONALLY RICH, MEDIATED SPACE.

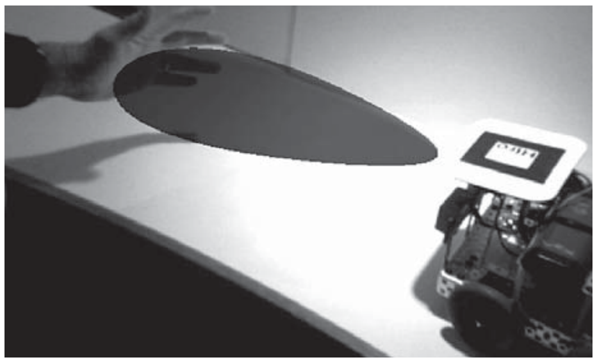
This principle addresses the spatial qualities of the cybrid and the ability of users to generate spatial experience from a variety of informational sources. Users who can, for instance, see the virtual blimp, know the set range of the ultrasonic sensors. In this way their senses have been extended to include ultrasonic frequency, if only through the corroboration of technology and users' innate ability to translate information spatially information.

Sensory extension is an important motivation for AR research. Grant Foster and his colleagues at the University of Reading and, later, Steve Mann of the University of Toronto have used Augmented Reality to make hot areas visible to users (Foster et al. 1998; Mann 2002). The use of Augmented Reality to detect invisible objects has also led to systems that can be used in fighting fires, surgery, and locating objects in murky water (Giannitrapani et al. 1999; Bimber and Laskar 2005). In these cases the users' senses extend beyond their normal range through Mixed Reality technology.





FIGURES 8 AND 9 The robot has two ultrasonic sensors that detect distance. The cardboard top of the robot has a fiduciary icon used by ARToolkit to locate the virtual component. The oblong shape shown on the right is the virtual part of the cybrid. It is three-dimensional and maintains its location with respect to the robot as though it was a physical element of the composition. (see Fig.11)



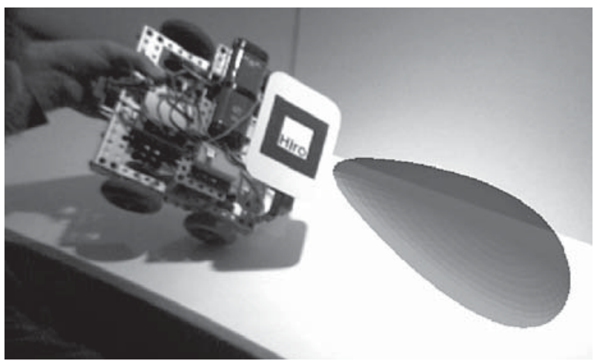
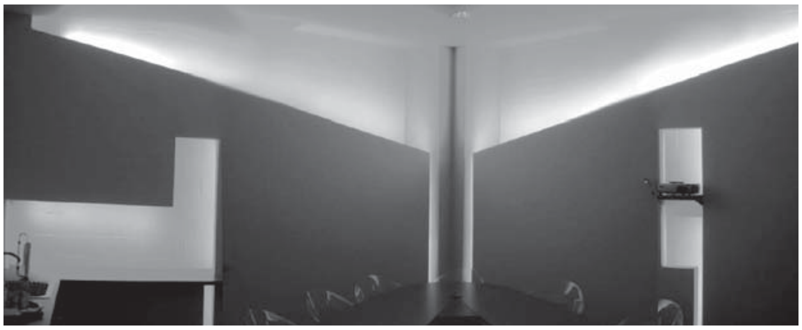
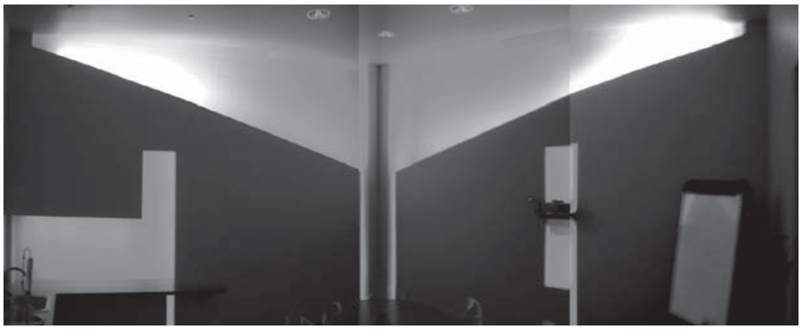


FIGURE 10 AND 11 These images show how the physical and virtual parts of a cybrid act reciprocally. Pushing or pulling on the virtual portion causes the physical robot to advance or back up. Manipulating the physical robot affects the virtual object as well as seen on right.



FIGURES 12 AND 13 These images show LED lighting in the office conference room (left) and the entry way. Colors in the spaces go through full rainbow cycle in one hour in the conference room, over eight hours at the entry. The two spaces are coupled through motion detectors and a shared processors.



FIGURES 14 AND 15 Visitors in one space cause a slow, spreading cloud of white light in the other space. These images show the lighting in each space with the moving cloud. The effect lasts about ten seconds before fading away.

6. SOCIAL CONTEXT: CYBRIDS PROVIDE AN EXTENDED SOCIAL SPACE.

If by *invisible objects* we also include remote entities, we open the door onto the sixth principle, social context. Architectural cybrids may form social spaces that integrate physical and cyberspaces. Beyond sustaining the activities of its occupants, cybrids may provide tele-present users with a context for interacting with physical occupants. This was the intention behind the design for the Planetary Collegium project, the office space, and the playhouse.

Of the three projects virtual presence is only manifested in the office space. Sensors and processors in the conference room and entry activate LED lighting in the counterpart space (Figures 12 and 13). For instance, if the conference room is occupied, lighting changes color in the entry hall. Conversely, if someone is in the entry hall, the color of the conference room lighting changes subtly. It was originally thought that visitors to the company Web site would affect the lighting in the entry hall as well, effectively *haunting* the lobby via cyberspace. Although this feature has not been realized, it suggests historical/anthropological models for interaction with non-physical presences. Future interaction might be based on myth, legend, or even occult practices.

7. ANTHROPIC DESIGN: CYBRIDS SHALL BE DESIGNED TO AUGMENT THEIR USERS' INNATE USE OF SPACE TO THINK, COMMUNICATE, AND EXPERIENCE THEIR WORLD.

Anthropic cyberspace has been defined as "an electronic environment designed to augment our innate use of space to think, communicate, and navigate our world" (Anders 1999, 9-10). The seventh principle expands upon this definition to include both the material and cyberspatial aspects of cybrids. While our first principle addressed the comprehensive space of the designer, i.e. the mental/virtual/physical space, this one does so for the user. The seventh principle stresses the way we make sense of the world through spatial experience. It recognizes space as a product and tool of consciousness, a medium shared by designers and users alike.

CONCLUSIONS

The principles and projects above illustrate issues designers may encounter in a mixed reality project. Needless to say, designers have considerable leeway in how they apply the principles. As we have seen, a project's integration of physical and virtual components depends on design priorities, budget, and the technologies involved. Of the projects shown, for instance, only the robot demonstrates strong reciprocity. Several of the projects still await fuller development of their virtual spaces—especially their social use.

The projects helped test the cybrid hypothesis and led me to some unexpected solutions. In building the robot I found that using two off-the-shelf processors and programs got me around having to specially develop integrated software for the cybrid. The robot's processor, for instance, handled motion detection and locomotion, while the laptop processor handled imaging. The two processors simply did their jobs without communicating with each other. The coincidence between motion and graphics, "integrated" the robot and virtual object in the mind of the observer. This inferred link between phenomena shows how important consciousness is in completing the composition. It appears that with advances in ubiquitous computing similar redundancy of processors in our environment may have unexpected, magical effects.

ACKNOWLEDGMENTS

The author wishes to thank Werner Lonsing and Hirokazu Kato for their encouragement and generous support in the projects described in this paper.

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