

AmbiViewer: A Tool for Creating Architectural Mixed Reality

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Introduction

Merging digital and physical environments in a blended reality is a focus of inquiry among technologists, artists and designers. This technology, known as augmented, or mixed, reality (AR and MR respectively) has appeared in venues ranging from computer labs to gallery installations since the early 1990's. In this paper we will describe the creation of a tool for architects to create three-dimensional compositions – full scale objects – on actual sites, and to view the results as navigable mixed realities. This tool, we argue, presents an important opportunity for conventional and computer aided design processes. Its implications reach beyond imaging and fabrication to suggest alternative architectural products, ones that fully engage the mixed realities of contemporary culture.

This paper will describe the potential use augmented and mixed reality in architecture, and presents a performance specification for an apparatus that supports architectural design. We will follow this with a description of an MR system called *AmbiViewer* with a discussion of its hardware and software subsystems. At the end is a description of a small project undertaken to evaluate the system's performance in the design/creation of mixed realities. Concluding remarks will discuss projected developments for *AmbiViewer* as a tool for designers and creators of mixed realities. Before proceeding, however, we should first define the terms we will be using.

Terminology

Our topic, the merger of material and simulated elements, is known in the literature as augmented or, alternatively, mixed reality. Augmented reality (AR) often employs transparent displays that overlay computer graphics onto the viewer's visual field. It has been used in the development of heads-up displays for equipment repair, in surgery that

allows physicians to see into their patients' bodies, and as a means for discerning damaged pipes in murky water. While visual technology predominates in AR, some forms of augmented reality overlap the sense of sound and touch as well. The visual focus of AR is a challenge to its engineers. If the overlaid graphics are linked to external objects, a moving viewer's head and gaze must be tracked to maintain a consistent illusion. The spatial relationship between the external environment, the display, and the user's senses is crucial to the effect. For instance, a user of a HMD (head-mounted display) may be simultaneously aware of 1) his physical surroundings, 2) virtual objects that map onto physical objects, 3) virtual objects that float independent of the physical space, 4) and virtual objects that are fixed parts of the visual display – such as a menu or icon. Sophisticated tracking of the viewer involves sensors, whether they be motion detection systems, microwave detectors, Global Positioning Systems (GPS), and other means or combinations thereof. Importantly, the user's bodily and cognitive use of space keeps the experience from being chaotic. The experience of a coherent, comprehensive space is maintained. [Anders 2003]

Mixed reality refers to a spectrum of synthetic physical/virtual experience. Paul Milgram and Herman Colquhoun Jr. of the University of Toronto have developed a helpful taxonomy to distinguish mixed reality's varied effects. [Milgram and Colquhoun 1999] It is situated within a larger scale of experience, one that extends in their argument between "real" and "virtual" environments. Milgram and Colquhoun's description of mixed reality offers a variety of hybrid effects ranging from Augmented Reality on the "real" side of their real/virtual scale, to Augmented Virtuality (AV) on the "virtual" side. Augmented Reality, we noted, overlays virtual elements onto physical environments. Conversely, Augmented Virtuality, overlays "real" elements onto virtual environments. The effects of AV would resemble special effects in contemporary film, where images of real actors are collaged into animations or computer-rendered sets. The degree to which the viewer interacts with the result – whether AR or AV – determines the result's effectiveness as a mixed reality. Whereas virtual reality closes the user off from physical surroundings, most mixed reality opens the virtual world to the immediate environment. The resulting

montage hybridizes the user's experience, and at its extreme blurs distinctions between simulation and actuality.

Architecture and Augmented Reality

In the eyes of AR's developers the construction industry offers a promising market for the technology. Their reasoning is straightforward: AR deals with spatial and symbolic phenomena in ways potentially useful to architects, builders and facility managers. These industries' increasing familiarity with – and reliance upon – computers makes them well suited for mixed reality technology. However, as with virtual reality before it, the success of such forecasts hinges on a variety of issues. Some of these lie outside the domain of technologists: compatibility, reliability, flexibility, and purchase costs, training and upkeep. Not least important is the degree to which AR systems serve the needs, and values of architects and their clients.

The overlay of spatial computer models onto buildings has uses in nearly all stages of the building's life. A project's database may facilitate a building's design, its construction and maintenance. Computer scientist Gudrun Klinker suggests that a project's mixed reality would attend all stages of development, from the earliest siting of a building to its subsequent occupation. In a paper written on uses of augmented reality models on construction sites, Klinker and her colleagues speculate on AR's use in the building's life cycle.

“With AR, ... virtual geometric objects can be integrated into the real environment during all phases of the life cycle of the building. Before the construction project is started, AR can support marketing and design activities to help the customer visualize the new object in the environment...During construction, AR can help evaluate whether the building is constructed according to its design...After construction is completed, maintenance and repair tasks benefit from seeing hidden structures in or behind walls.” [Klinker, Stricker, Reiners 1998]

This bears directly on the life-cycle of an architectural project, stressing the digital model's role in constructing and serving buildings. The use of virtual models as annotational guides for construction is prevalent in AR literature. Indeed, among the earliest uses for AR was in overlaying instruction manuals onto the viewing field of factory workers at Boeing. (Curtis, Mizell, Gruenbaum, Janin 1999) (Mizell 1997) Subsequent work by others illustrate the use of AR for the repair of copy machines, door assemblies and other equipment. [Reiner, Stricker, Klinker, Müller 1999] [MacIntyre and Feiner 1996] [Molineros, Raghavan, Sharma 1999]

Seeing the invisible

Among other virtues of mixed reality is the ability of its users to perceive invisible aspects of their surroundings. Grant Foster and his colleagues at the University of Reading have described the uses of a simulation overlaid onto a building. They have developed DAMOCLES, a system that enables vision or hearing impaired users to navigate a building by aural and visual cues. [Foster, Wenn, Harwin 1998] Beyond helping the blind, however, Foster believes that AR systems can let users see the invisible. Equipment that generates heat, for instance, can be visually augmented to keep operators from harm. Such thinking lies behind similar proposals for visualizing the invisible. [Kieferle and Wössner 2001] Professor Anthony Webster at Columbia University has also explored the use of AR in architecture – particularly in the field of construction. With colleagues Stephen Feiner and Blair McIntyre, he was able to render to view the hidden reinforcing rods in a concrete column using a head-mounted display. [Feiner, Webster, Krueger, MacIntyre, Keller 1995] The ability to see through obstacles, such as concrete, murky water, or human flesh is a constant theme in AR's literature.

Just as Klinker and others project a site's future with augmented reality, its past may be similarly revealed. Feiner and his colleagues at Columbia have modeled the campus of their university as an armature for historical research. Using a heavy, but mobile, AR system users navigate the campus and “see” buildings torn down years ago, or they can

explore the school's underlying tunnels that proved vital in the 1968 student uprising. [Feiner 2002]

Mixed reality has also found uses in telecommunications. A number of researchers including Jaron Lanier have developed a desktop augmented reality, called teleimmersion, that lets users converse with remote colleagues by using an elaborate screen display. The user is able not only to see a partner, but, by moving his head, can view the remote space as though through a connecting window. The effect is apparently quite convincing since the virtual images are taken from a number of corroborating video cameras. [Lanier 2001] This, plus the extremely high speed of the advanced Internet connection makes the presence of the distant space almost palpable. This combination of social space and telematics suggests architectural mixed realities that have been termed *cybrids*. [Anders 1999] (Fig. 1)

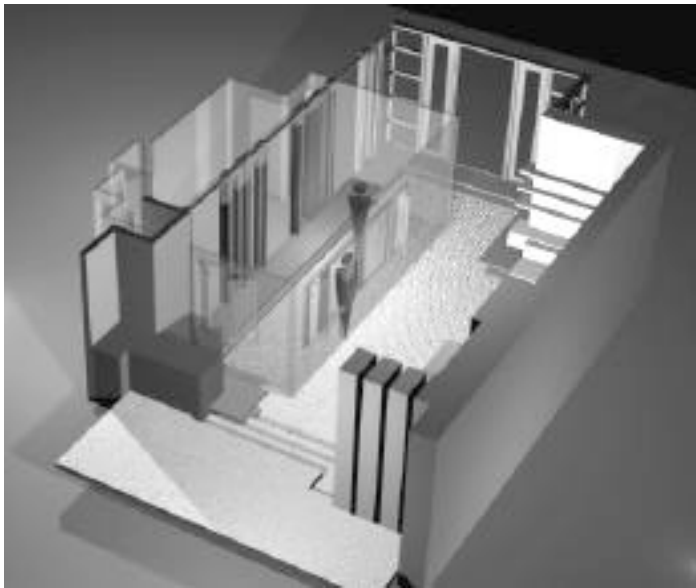


Figure 1. Image of a cybrid showing construction and cyberspace (on left) used for telepresence. The remote space is replicated as a virtual annex to the physical space.

Architectural Needs / Opportunities for AR

It is apparent from the foregoing discussion that AR has much to offer architects. AR may indeed affect all stages of a building's construction and use. Presumably, a mixed reality could inform the architect's design from the project's onset. But this is not so easy as it might seem. Although AR technology allows three-dimensional models to be sited in

actual space these models require prior design decisions and articulation before they can be merged into the scene. As a result, AR design cannot begin until fairly late in the design process. This is unfortunate because the earliest stages of design are highly information sensitive and would appear to benefit most from digital assistance.

There are several reasons that AR use is limited at this stage of design. Much present research on Mixed Reality is not devoted to design exploration so much as developing effective illusions: end products such as animations, installations, or other special effects. The virtual components of these mixed realities are pre-designed. In architecture, however, the virtual, imagined objects of design are not set at the beginning of a project. Spontaneity, inspiration and indeterminacy characterize this phase. There is an opportunity, then, for creating a mixed reality sketching system that lets users compose designs spatially, spontaneously, and on site. Solutions so created could then apply to future stages of the project. Developing such a system requires a performance specification based on the perceived needs of designers at the initial stages of a project. These needs include portability, ubiquity, visualization, and indeterminacy and are summarized below.

Portability

Conventional sketching is done with materials that can easily be carried from place to place: paper, pencil, sketchpads, etc. Many current AR systems depend on a fixed infrastructure (lab space, tracking systems, desktop computers) for their performance. An AR sketching system, while not as concise as its sketchpad counterpart, must at least be portable by one person and allow flexibility in setup and use. Any dependency on fixed infrastructure on site – tables, outlets, and cable connections – should be minimal.

Ubiquity

As mentioned, many current AR systems require a stable sensor environment to track the user's camera or head mounted display. This often entails an indoor environment that – in turn – limits the apparent size of an effective virtual object. A full-size simulation of a sited building does not conduce to a lab setting, for instance. The AR system must be

independent of fixed transmitters that would limit its use to specific locations. Ideally such a system could be deployed anywhere.

Visualization

Visualization here refers to inscribing an image or design so that it might be assessed for later use in the design. Pencil and paper provide an ideal model for an input/output system, however, design intent is necessarily shown statically from a particular viewpoint, and solely as inscriptions on a page. An AR system should provide such visualization capacity, while letting its user explore the design – effectively sculpting it from multiple vantages – rather than fixing it with unrelated sketches. The three-dimensional digital models are a useful example of computer-assisted visualization.

Indeterminacy

We have already discussed the need for the spontaneous use of AR in sketching designs. This entails creating a system in which virtual elements of the mixed reality are created on the fly and not simply ported in from other applications. While such an exchange would be useful in later design stages, a sketching system must have on-board modeling capacity.

A system that meets these needs has been under development since the mid-1990's. Over the past year we have collaborated in developing and testing the results of this effort, *AmbiViewer*, a tool for designing and creating Mixed Reality.

The System

The configuration of *AmbiViewer* resembles those found in other augmented reality setups. Like them it requires computer processors, user tracking systems, display and rendering software. For economy the display system is presently limited to computer monitors, although a worn display will be preferred in the final configuration. Another feature that distinguishes the system is an interactive modeler that allows real-time creation and manipulation of virtual objects. Necessary hardware includes 1) tracking

devices, like GPS or similar, to concurrently determine positions of objects and users, 2) digital cameras as real-time image capturing devices, 3) fiduciary features that act as reference objects and 4) at least one computer with display.

In our present application the hardware devices are integrated by use of several layers of software. These include software for 1) determining positions of cameras and fiduciary features, 2) image capturing, 3) image processing to identify and evaluate features, 4) interactive modeling of three-dimensional objects, 5) rendering perspective views of the model depending on generated values, and 6) composing the captured and rendered model into composite images.



Figure 2. Digital video camera with GPS receiver attached at top determines viewer location, direction of view and focal length. Smaller laptop-mounted cameras have since been used to minimize weight and inconvenience.

Portability and Ubiquity

The system in its current form is fairly portable, using batteries rather than power outlets with no need for physical connection to a positioning system. It is possible at this time to obtain wireless connection to the Global Positioning System (GPS) using Bluetooth. Excluding the weight of a laptop computer, the system weighs only ounces: a small GPS tracker, digital camera, and a visual marker (a balloon or ball). It may easily be transported on foot in a knapsack, or in a car. (Fig. 2)

Because of the need for outdoor use and the architectural scale of the subject matter we required a positioning system that was external and flexible. AR commonly employs controlled environments with customized technologies fitted to the setup. For our uses,

however, we required that our outdoor tracking system be both affordable and robust. The Global Positioning System effectively makes the surface of the Earth a controlled environment through the use of situated satellites. GPS's use in AR has precedents in the work of S. Feinman, B. McIntyre, B. Jang, R. Azuma among others. It enhances the mobility of our users and their equipment, freeing them to visit the building sites of their choice. The present system is well suited to the scales of architecture, civil engineering, and regional planning, and we anticipate its use in siting buildings, bridges and infrastructural elements.

Changing locations of viewers and features is efficient and affordable with the system. Under normal circumstances GPS results in signal delay intervals of about one second and an accuracy within three meters. In more developed areas where Differential GPS (DGPS) is available – the United States and Europe for instance – submeter accuracy is standard. DGPS systems are bulky and would mitigate against our need for portability. Also, since DGPS systems are presently expensive we have for now limited our focus to the conventional accuracy of GPS for camera and fiduciary location. (Fig. 3)

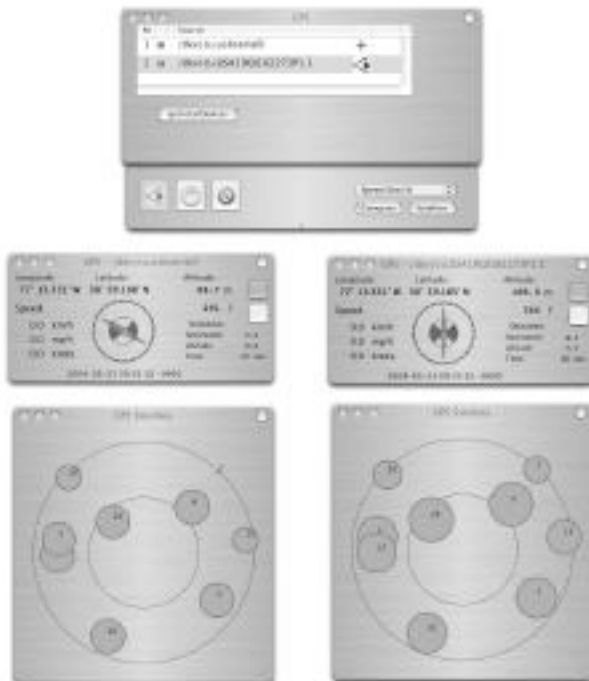


Figure 3. Interfaces for two concurrent GPS locations, one for the fiduciary feature, the other for the viewer camera. AmbiViewer allows simultaneous tracking and location. Each GPS unit can display the satellites used in setting the location and direction, below.

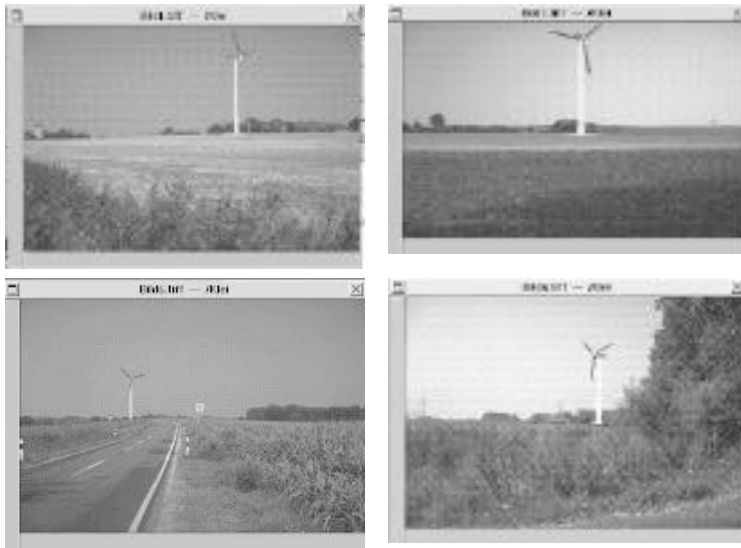
There are other ways to get this accuracy without the expense and difficulty. R. Azuma observes that greater degrees of accuracy outdoors require a hybrid approach to technology. [Azuma et al 1999] For this reason our system employs a visual fiduciary tracking subsystem to compensate for GPS uncertainty. This results in a surprisingly effective, if rough, measuring tool. At present GPS precludes indoor tracking because receivers require line-of-sight access to the satellites. That said, we are still in the product's development and further hybridization remains an option for indoor use.

Visualization and Indetermination

Composite images that combine actual and imaginary objects or scenes are a special form of visualization. While conventional sketches do not distinguish between real and virtual elements, analogous AR compositions present a number of special challenges. Composite images in AR require an input source, a digital camera, a modeling source and a three-dimensional rendering engine. In addition the source and model images must be convincingly combined into one image. Because live-streamed video is the only adequate image input for a real-time application, the captured stream has to be assessed frame-by-frame in order to detect, identify, and evaluate the features using methods of image processing, including Hough Transformations. Such image processing is demanding and creates a significant bottleneck in many AR applications. It puts the entire computational load on the CPU and requires a selective use of data. Only focal length and exact viewing positions are generated using the fiduciary feature while other, possibly valuable, input must remain unused.

Happily, generating a real-time 3D model is no longer a problem for AmbiViewer. By creating an object-oriented modeler completely based on OpenGL, the former bottleneck of 3D rendering is overcome. The final steps of image processing are executed on the graphic card, or GPU, using its processor and memory. While the video stream is buffered in the card's memory, the model is rendered using the OpenGL instructions already implemented. Composing the captured and generated images into a composite

scene is then a comparatively simple matter of combining both buffers in the right order and displaying the results onscreen. Because of the uninterrupted flow of the process nothing can be corrected; the quality of the final composite is directly related to the quality of the video stream and generated images.



Figures 4, 5, 6, and 7. These images show a simulation set into an actual landscape. The study was done to assess environmental impact of the proposed windmill. It was possible to view the mill from all angles and distances using the system.

Calculating the perspective views from the on-site location is the major task of the software and the quality of the result depends largely on the accuracy of calculated spatial and temporal values. This accuracy is helped by using GPS to assess user position and the fiducial feature to determine the focal length and exact direction of view. (Figs. 4, 5, 6, 7) To add to the realism of the virtual model we can employ GPS to determine sun position, or add atmospheric values via the fiducial system. These GPS values, refined by those obtained from the fiducial feature, are directly applied in the modeler and employed in the rendering. However this added task, while improving realism, burdens the processor already encumbered by dataflow management and geometric control of the model. Presently this option decreases the overall performance of the system, although it remains an option as computational power increases.

The current configuration of AmbiViewer opens a number of variables to the user including site and viewing locations, number, size, shape and color of virtual components, and their situation within the spatial setting. Most importantly, the user has live control of the virtual elements beyond viewing angles and camera movement.

Creation of new elements, modifying or moving existing ones, or deleting unwanted objects is done in real-time within the application and always in view of the site. This freedom provides the user with the creative indeterminacy required at the earliest stages of design. In addition users can, in the course of modeling, archive the design process as a video for later reference, a feature that could be useful for educators as well as practitioners. Users could also easily access and re-do prior states of the virtual model through use of this “time-stamp” record.

A Design Experiment

In the summer of 2004 we undertook a small project – a playhouse – to test the system’s use in the design and creation of an architectural mixed reality, or cybrid. At this time the system had support from GPS for its camera system. Although it was hard to



Figure 8.
An initial sketch using Ambiviewer. The bottom ball on the ground is the fiduciary marker for the mixed reality. The rest of the balls and cylinders are simulations.



Figure 9.
The design of the playhouse shown under development in the Ambiviewer composition screen. The panel on the right allows creation and control of new objects in the scene. Note red fiduciary marker.



Figures 10 and 11.

Shown at left is the playhouse as built. Below is the playhouse with situated 3D elements using AmbiViewer. Such sketches will inform the cyberspace of the cybrid playhouse.



calibrate precisely, the modeler did allow the rough massing of elements on the site. After preliminary efforts at placing arbitrary objects in the yard (Fig. 8), a suitable site and preliminary scheme emerged. (Fig. 9) Since the AmbiViewer version employed had no ability to export the model to other applications, the structure was built in ensuing weeks from sketches based on the AR model. (Fig. 10) Successful enough as a playhouse, we intend to use the physical shelter as a “site” for virtual additions. (Fig. 11) We anticipate that AmbiViewer would make such cybrid compositions possible and “real” to observers, especially if other systems are involved for realizing sound and tactility.

Conclusions

We have here presented an architectural authoring tool that employs Mixed Reality concepts to situate simulations into actual settings. Using GPS and fiduciary features we have attained sufficient accuracy to model and locate designs for construction, autonomous simulations or hybrids of physical and virtual elements. An on-board

modeler not only lets us generate these products, but lets users manipulate the virtual elements interactively, even after a project is completed. The resulting configuration is a flexible and adaptable environment suiting the needs of its users. As the system is further integrated and its portability improved, we look forward to developing means for direct fabrication of physical and virtual elements of the cybrids and their user interaction.

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