

MxR A Physical Model-Based Mixed Reality Interface for Design Collaboration, Simulation, Visualization and Form Generation

Augmented Reality

Collaboration

Interactive
Interface

Physical Modeling

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MXR—PRONOUNCED “MIXER”—IS A MIXED/AUGMENTED REALITY SYSTEM INTENDED TO SUPPORT COLLABORATION DURING EARLY PHASES OF ARCHITECTURAL DESIGN. MxR allows an interdisciplinary group of practitioners and stakeholders to gather around a table, discuss and test different hypotheses, visualize results, simulate different physical systems, and generate simple forms. MxR is also a test-bed for collaborative interactions and demonstrates different configuration potentials, from exploration of individual alternatives to group discussion around a physical model. As a MR-VR transitional interface, MxR allows for movement along the reality-virtuality continuum, while employing a simple tangible user-interface and a MagicLens interaction technique.

1 Introduction

In the important early phases of design, designers frequently struggle to acquire, visualize and integrate as much information as possible about their project. Increasingly, team-based collaboration and numerical simulation and visualization are employed as means for assessing or predicting building performance. Animated conversations around conference tables, supported by sketches, gestures, words, eye-contact and “hard data” play a significant role in shaping the final product, but are sometimes hindered by the “digital” vs “physical” interfaces to information.

In this project we have divided collaborative architectural design activity into four categories: communication, visualization, simulation, and form generation. *Communication* describes the process of exchanging ideas, concepts, facts, or desires through media such as language, gesture, text, images, video, etc. Simulation, refers to the process of computationally forecasting the results of a given design choice. By *visualization*, we refer to the process of generating images, static or moving, of geometry and/or data. *Form generation* refers to the activity of shaping objects, spaces, and places. These categories are not mutually exclusive and many CAAD tools seek to facilitate one or more in some way, but none is able to do so without constraining the very human conversations that form the backbone of the process. In this paper, we present MxR, an interface that seeks to mix all four aspects into one single intuitive interface centered around the practice of viewing a physical architectural model as a locus of communication.

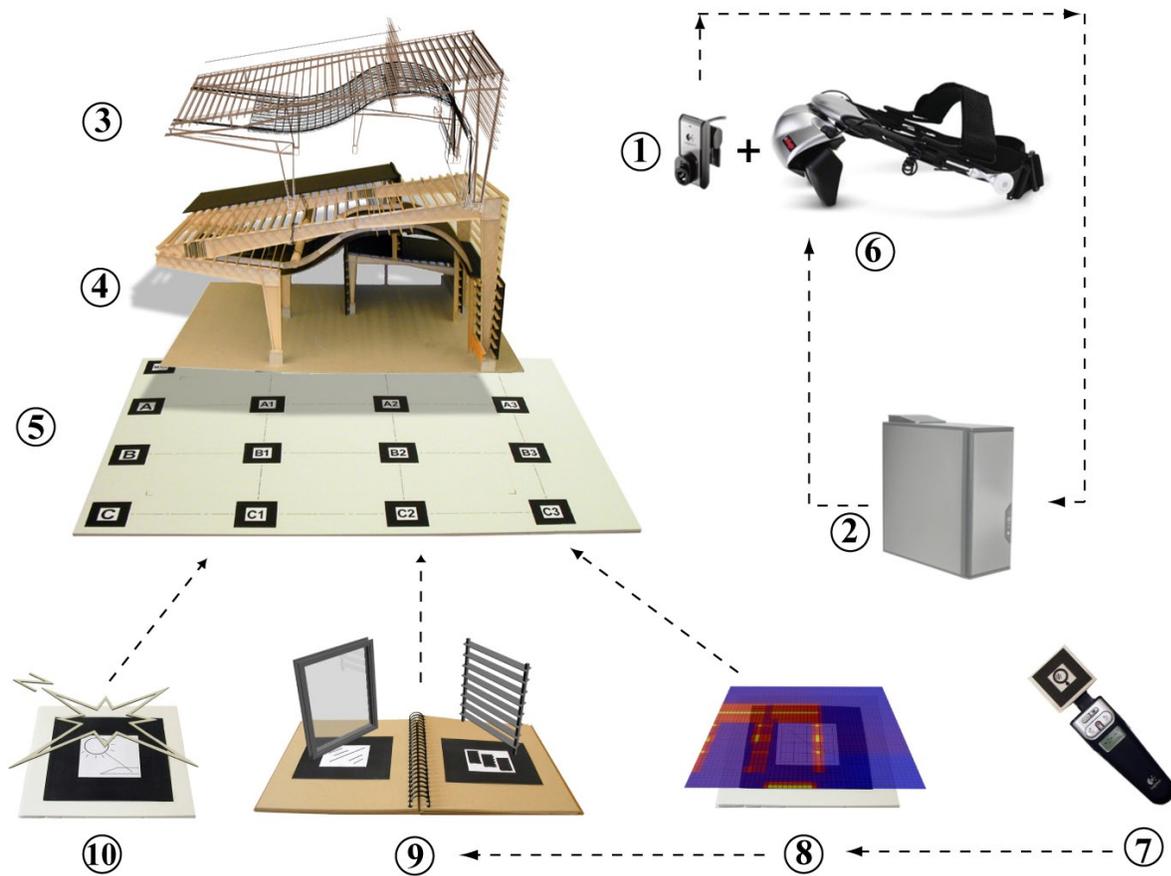
2 Related Work

Mixed Reality (MR) or *Augmented Reality* (AR) is the process of viewing the real world and virtual objects simultaneously, where the virtual information is overlaid, aligned and registered with the physical world (Azuma 1997). The application of MR/AR to the architectural design process is not novel. Early attempts focused on *in situ* viewing of architectural and construction elements in real spaces (Webster et al. 1996). Though *in situ* viewing is still an interesting area of inquiry (Malkawi and Srinivasan 2004), recent research has focused on the use of Tangible User Interfaces (TUIs) in AR and design. For MxR, we have adopted a TUI-based AR interface because it reduces the hardware demands of the system (relative to that of mobile *in situ* AR) while still addressing the core problem: representation of building geometry quickly, efficiently, while supporting intuitive interactions. TUIs offer direct manipulation of real objects, with clear benefits such as reduced cognitive load and a shallow learning curve (Kato et al. 2000).

Collaborative AR interfaces are effective because the task space is embedded in the communication space. Natural communication behaviors, such as gesturing, pointing, and gazing are preserved with face-to-face AR. Experiments have shown that there are direct gains in ease and efficiency when AR is coupled with a TUI and employed for spatial tasks (Billinghurst et al. 2002).

Seichter’s work on sketchand+ (2003) attempts to capture the practice of sketching in 3D using an AR interface. In later work, Seichter transformed the sketchand+ interface into Benchworks (2004), a system more suited to urban planning than sketching. The work of Broll et al. (2004) is among the few ambitious projects that attempt to capture the full spectrum of design collaboration within a studio environment. For MxR, we adopted a similar strategy to that of Benchworks—in its use of a collaborative tangible AR interface—but at the architectural scale. MxR takes many of its cues from both Broll and Seichter but centers interaction on a physical model (Figure 1.5) using a TUI.

Though MxR employs a basic TUI, we have also introduced an amount of abstraction to our interface in the form of a MagicLens (Figure 1.7). MagicLenses have been shown to be very effective at information filtering and semantic zooming (Bier et al. 1993). MxR’s 3D MagicLens is an extension of that developed by Looser (Looser et al. 2004). Though the 3D MagicLens is itself tangible, it represents a tool with specific affordances within the interface (described below).



3 MxR Architecture

The intended location for MxR is a meeting room or a studio space wherein groups can gather around a table and freely move to different angles. Any space that can accommodate a medium-to-large physical model should accommodate MxR.

3.1 EQUIPMENT

MxR uses a video-based MR/AR configuration: a webcam attached to a head-mounted display, both connected to a PC running the ARToolKit software. For MxR, a Logitech QuickCam Pro for Notebooks (640x480 resolution at 30 frames per second—Figure 1.1) mounted on an eMagin Z800 (800x600 resolution with a 40 degree field of view—Figure 1.6). The PC (Figure 1.2) is a 3.6 GHz Intel Core2 Duo PC with 4 GB RAM and an NVidia Quadro FX 4500 video card. The AR view provided by this system is monocular. All visualizations were generated with ARToolKit 2.72, osgART 1.0 (Looser et al. 2006), and OpenSceneGraph (Osfield and Burns).

All ARToolKit fiducial markers are printed in black-and-white and mounted on foam core (Figure 1.5). This main set—which we have dubbed “the platform”—is the site upon which different physical models are placed and aligned; a multi-marker set was used to avoid loss of tracking due to occlusion. All models are tagged with a discrete marker for identification.

One single smaller fiducial marker is mounted at the top end of a Logitech 2.4 GHz Cordless Presenter USB device (Figure 1.7) to form the MagicLens. The buttons on the device are mapped to specific MxR HUD control events. The device is easily operated with one hand and is meant to mimic the shape and feel of a magnifying glass.

3.2 SYSTEM CONFIGURATION

The MxR system presupposes that a design team has generated at least the most rudimentary physical or digital model—preferably both. These models need not be at an advanced stage of development; in fact, the rougher the models, the more support MxR can

FIGURE 1. MxR SYSTEM SETUP AND EQUIPMENT.

provide. Before starting the system, an indexed marker tag must be mounted in a visible location on the physical model. This tag is associated with a specific 3D model counterpart in the database.

MxR is centered on the “platform.” The “platform” allows participants to load different physical models or marker sets onto the tracking surface. When the model is placed in the center of the “platform,” the MxR system queries its database of pre-loaded models and switches to the relevant one, superimposing the virtual 3D model over the physical counterpart.

In this project, due to the high computation cost, all lighting simulation data were pre-compiled using Radiance (Ward 1994) and Ecotect (Marsh 2000). These data were then fed into the MxR system and associated with the specific models and design conditions. Due to the large number of potential permutations that the MxR system can produce, the most probable were pre-computed using a LUA script and the Ecotect Radiance Control Panel.

If available, the site context model can be loaded as well. For our purposes, we used a simple site model with a terrain contour map and extruded buildings from GIS data.

4 MxR Experience

All MxR users don HMDs and view the ambient environment as captured through the eye-level mounted webcam. Virtual objects are superimposed over the fiducial tracking sets to provide the Mixed Reality view. Since the user is wearing a HMD, both hands are free. Interaction with the model is achieved in two ways: 1) by moving around or turning the platform upon which the tracking markers are located, and 2) by the use of a hand-held MagicLens tool.

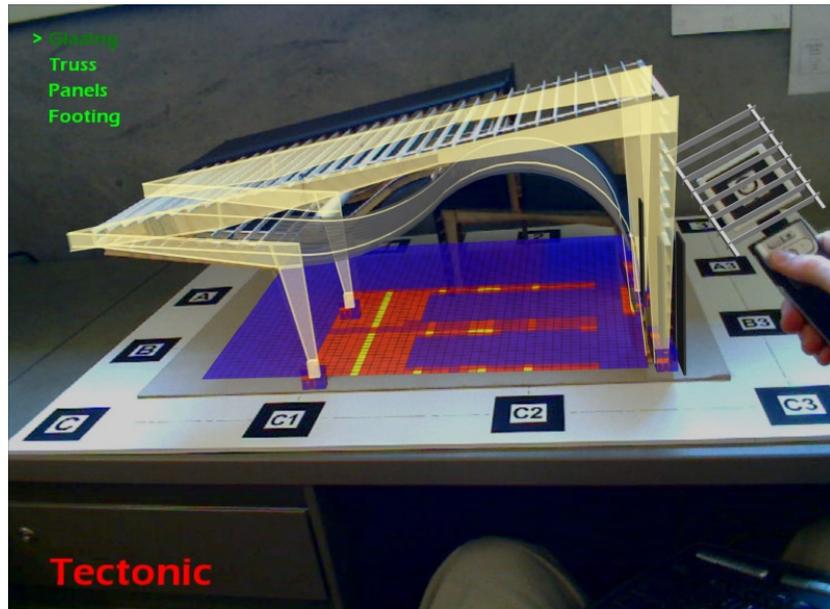
With the free hand, the user holds the Logitech Cordless presentation device, which serves as the MagicLens proxy. The single fiducial marker in this case represents the lens. Zooming in and out is as simple as moving the lens closer or further from the platform marker. The effect is that of using a giant magnifying lens on the side of a building. This device allows the user to filter different architectural layers, as well as zoom, pan, and highlight layers within the scene. A Head's Up Display (HUD) is located in the upper-left of the visual field displaying the currently active and invisible layers. The user can navigate through the HUD using buttons on the paddle (Figure 2).

Using the system, users may simply select and move geometric elements within the scene relative to the entire model. We have adopted a proximity based selection method as opposed to a ray-casting method. When the lens is moved through the scene, potential “selectable” components are highlighted with a transparent bounding-box. To select and manipulate the highlighted object, the user simply presses a button on the lens handle.

Changing opacity is also possible. Using the side button on the MagicLens, the user can increase or decrease the relative transparency of the selected layer. Changing the relative transparency allows the user to see through the virtual model to the underlying physical model. This allows for easy recognition of differences or discrepancies.

In addition to selecting, moving, rotating and changing transparency, the user can “explode” selected model components. This option may be used to illustrate the structure of compound objects. This is a simple animated effect without explicit semantic content, implemented by translating sub-object components away from their centroid.

In addition to the platform and model, the system recognizes a resource catalogue (Figure 1.9). This is a notebook of ARToolKit tracking markers, with each page containing a 3D model of a building component, a shading device, a species of tree, etc. The resource catalogue also contains a set of basic geometric primitives (box, sphere, cylinder, etc.) that can be positioned, rotated, and resized. By moving the paddle over the item, the user can select it and then—returning to the primary model—place it within the scene. The item will remain selected—so that multiple instances of can be placed—until the user shakes (moving the paddle rapidly from side to side) or selects another item. By default, the paddle switches back to the selection mode. To delete an item within the scene, the user can “swat” or “stamp out” the item with the paddle.



Time and environmental conditions are simulated. Attached to a separate fiducial marker is a virtual sundial (Figure 1.10). By rotating this marker relative to the “site” marker, the sun position can be changed to simulate different times of day. This marker works in tandem with another marker that controls the date.

While most of the experience of MxR occurs in the MR view, the participants can switch to a fully immersive VR view at any time (Figure 3). This is achieved by placing the paddle at a point in the model and holding down a button on the handheld device. The lens then flashes blue and the viewpoint is translated to that location and the video of the ambient environment is replaced by an immersive 3D view of the scene from the selected location. The eMagin HMD contains an integrated head tracker, allowing the user to look around and view the scene. At the same time, holding down the forward or back buttons on the handheld paddle translates the viewpoint accordingly. At any time, the user can switch back to the AR view by pressing the mode switch button on the paddle.

During design review it is often important to view the design in context. To achieve this, a separate tracking card is placed face down on the table. When flipped over to reveal the tracking marker, the site model is toggled on. In this mode, the user can employ the buttons on the tracking paddle to zoom in and out to gain a wider view. Switching off the site is as easy as flipping over the card.

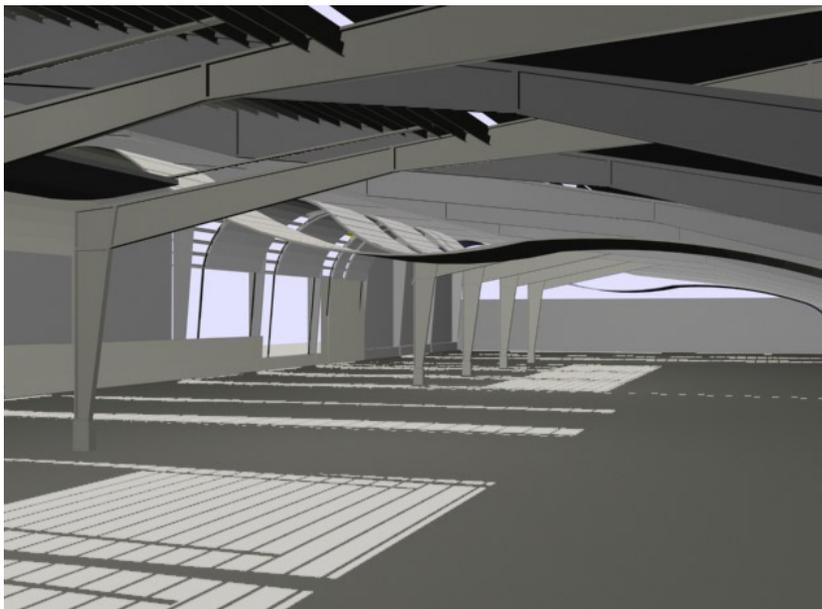
Simulation is currently restricted to lighting analysis. The user can select and place (using the paddle tool) an analysis grid. This grid is simply a mapped textured plane (Figure 2). By placing it in the desired location, the illuminance values (light falling on a surface) are displayed. The scale of values (in lux) is presented in the upper-right portion of the HUD. The participants can make changes to the configuration of the model—add or subtract window treatments, change the tint of glass, etc—and the simulation grid will dynamically update. To remove the grid, the user simply selects it (using the paddle) and drops it back on the tracking marker that serves as its holder. As indicated above, simulation of lighting values are currently pre-computed. While this may seem like a technical workaround, it is merely to illustrate an interaction potential implied by dynamic real-time lighting simulation.

Finally, at any time during the use of MxR, a snapshot can be taken. This image is a screen-captured frame of the current first-person view which can be used as a reference at a later time or when the system is not in use.

5 Discussion

MxR effectively supports three modes of virtuality and visualization in the iterative pro-

FIGURE 2. FIRST-PERSON MIXED REALITY VIEW.



cess of design. Initially, the interface is peripheral or minimal. Users can simply discuss the physical model without augmentation. Then, as ideas begin to flow and alternatives are proposed, the MR/AR views become relevant and useful. Different alternatives are proposed and analyzed. Finally, fully immersive visualizations are provided through the transition from AR to VR. There are a number of use scenarios where this process along the reality-virtuality continuum would be useful.

MxR establishes a bridge between the physical and digital models. MxR's strength is the facilitation of group discussion around this mixed model. As MxR is intended for collaborative use by individuals of varied disciplinary backgrounds and technical skill levels, little if any instruction is necessary for basic viewing tasks. A small amount of instruction is needed—which of the 6 buttons perform which operations—to perform relatively complex tasks quickly. This should be compared to the time necessary to learning the menu system of a desktop-based GUI.

MxR effectively allows for the exploration of alternative testing and iterative early simulation. The lighting simulation information provides the user with a consistent flow of data that form the subject matter and background of subsequent design decisions. By cycling between different façade and window treatments and examining the resulting lighting conditions over time, both qualitatively and quantitatively, decisions about day-lighting can be made early on in the process with relevant supporting data.

Alternative material testing is also well supported. Because the user can switch between conceptual (non-augmented) views of the physical models and mixed reality views containing more accurate material visualizations, differences between the rough model and more refined and crystallized design decisions become evident.

At the current stage of development, MxR's largest weakness is form generation. Of all the design activities outlined above, MxR has only limited support for the generation of geometric primitives.

6 Future Work

The interface would benefit from a formal user-study. A set of tasks could be developed for dual-user face-to-face collaboration using MxR. A time/error efficiency measure should be employed along with protocol analysis of observed communication behaviors. Subjective questionnaires could also be used to evaluate user's perceptions of the system.

At this stage, MxR is limited to lighting simulation, and even this has been approximated through the use of pre-computed illuminance maps. However, these simulation data have shown promise to lead to design insight when provided in an intuitive fashion. In further

FIGURE 3. FIRST-PERSON VIRTUAL REALITY VIEW.

work, we would like to explore visual metaphors and interaction techniques for simulation of additional physical systems such as weather conditions and airflow using Computational Fluid Dynamics (CFD).

Evaluative simulation need not be limited to physical systems. We would also like to implement a basic agent simulation system to examine circulation and basic behaviors within the design. Just as is the case with lighting and CFD, we predict real-time agent simulation to be computationally expensive at a large scale. Previous research (Broll et al. 2004) has demonstrated the utility of agent modeling in collaborative design process. We predict that agent behavior models, if coupled with lighting and CFD simulation, would provide a rich experiential sandbox for the collaborative design team.

7 Conclusions

We have presented MxR, a collaborative Mixed Reality system for visualization, communication, simulation and form generation within the early phases of design. MxR is a test-bed for Mixed Reality interactions around a physical model. We have outlined the interactions of the system and called attention to shortcomings with regard to form generation. Even at an early stage of development, MxR shows promise to support early iterative use of lighting simulation and real-time visualization of alternative architectural configurations to explore design alternatives.

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