AUGMENTED REALITY VISUALISATION FACILITATING THE ARCHITECTURAL PROCESS

Using Outdoor Augmented Reality in Architectural Designing

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Abstract. This chapter presents an overview of how augmented reality can improve the visualisation of architectural designs. An overview of wearable computer technologies and augmented reality is provided for a better understanding of the technology. The Wearable Computer Laboratory’s Tinmith wearable outdoor augmented reality backpack system is described to reveal the current state of the art in this form of technology. The key contribution of this chapter is an explanation of how the user of a wearable augmented reality computer system can facilitate the architectural design process.

Keywords. Augmented Reality, Wearable Computers, Architecture, Visualisation.

1. Introduction

The revolution of wearable computers (Bass et al., 1997; Thorp, 1998) and light-weight head mounted displays (HMDs) over the past ten years has made it practical to take augmented reality (AR) (Azuma, 1997; Azuma et al., 2001) into the outdoors (Feiner et al., 1997; Piekarski and Thomas, 2003c). AR is the process of a user viewing the physical world and virtual information simultaneously, whereby the virtual information is registered to the physical worldview. AR has been employed in a number of domains, such as the military (Julier et al., 2000), surgery (Fuchs et al., 1998) and maintenance work (Curtis et al., 1998; Feiner et al., 1993). Bringing AR outdoors requires the coupling of global positioning system (GPS) receivers and digital orientation sensors with 3D graphical models. Systems such as Tinmith (Piekarski and Thomas, 2001) are spatially aware computer systems for mobile users working...
outdoors. I anticipate outdoor users requiring hands-free operation, and related AR applications are therefore particularly well supported by wearable computers and non-traditional input devices. A motivating application of these mobile AR systems is the visualisation of new architectural designs at the actual building site. This chapter discusses the process of using mobile augmented reality to improve the understanding of architectural designs through improved visualisation. Several systems are discussed, but the focus of the chapter is how Augmented Reality may help with this process. A number of constructed concept-demonstrator systems along with conversations with architects have determined the processes, which have been distilled down to a set of key points.

1.1. AUGMENTED REALITY

The key to making in-situ visualisation of architectural designs practical is augmented reality technology. Figure 1 depicts how AR works: the user’s normal visual stimulus of the physical world is combined with computer-generated images. An optical combiner via video camera images fused with graphical images by the graphics chip set on a notebook computer was employed. The final fused image is presented to the user through a traditional VR HMD. Figure 2 depicts an example of an AR view from the Tinmith system. Unlike VR, where the computer generates the entire user environment, AR places the computer in a relatively unobtrusive assistance role. Using a wearable computer with a video see-through HMD allows people to move freely while working. Using GPS and orientation sensor technology the computer gains an additional and important input, the user’s location, and thus computer applications gain spatial awareness that remain synchronised with the user’s own awareness.

Figure 1. Overview of Augmented Reality.
1.2. THE PROBLEM

How does one visualise the architectural design for a new building or a modification to an existing building relative to its physical surroundings? In the past, technical plans would have been made and models built. Current use of CAD packages extended this process to visualise the design of the building fully rendered as a 3D graphical model on a traditional workstation. Changes may be completed whilst the customer is in the design studio and the result may be visualised for the duration of this process. With the advent of Virtual Reality (VR), visualisations that are more ambitious were made possible. VR enables customers and designers to view a design in an immerse environment (Brooks, 1986; Mine and Weber, 1995) with the use of a VR head-mounted display. People are placed in a simulation and then simulate walks through the new design. They can visualise and move through the layout of the building in 3D. Tracking each user’s head, allows for an intuitive movement of the head to change the viewing direction. Treadmills allow users to move by walking through a design while still physically inside the design studio. Together, tracking and treadmills allow users to sense the size and position of features in a new design. However, how can a user place a new building or extension in context with the proposed building site? Digitally enhanced photographs can show the placement of a building with respect to one vantage point. Models may be built to provide more vantage points, but these are expensive and time consuming to create, and offer only an artificial rendition of the site.
1.3. THE SOLUTION

The solution that the Wearable Computer Laboratory employs is to allow a user to walk around the site where the new building is to be constructed and visualise this new artefact in the spatial context of the existing environment. AR may be employed as a technique to provide this visualisation. AR has been used before in visualising interior design information. Webster et al. (Webster et al., 1996) developed AR systems to improve methods for the construction, inspection, and renovation of architectural structures. Their initial experimental AR system shows the location of columns behind a finished wall, the location of re-bars inside one of the columns, and a structural analysis of the column. Like other researchers, Azuma et al. (1999) and Feiner et al. (1997), the Wearable Computer Lab of the University of South Australia is taking this use of AR from the indoor setting and placing it in the outdoor environment. The Tinmith system has been employed as a mobile AR platform to display architectural designs in an outdoor environment (Piekarski and Thomas, 2001; Thomas et al., 1999).

2. Background

Wearable computers have now progressed to the processing power available on desktop computers. Such systems are commercially available and combined with an HMD deployed to assist workers with tasks that require information to be presented while keeping the hands free. Systems have been tested in the field with studies such as those by Siegel and Bauer (Siegel and Bauer, 1997) and Curtis et al. (1998).

A key feature of a wearable computer is the ability for a user to operate the computer while being mobile and free to move about the environment. When mobile, traditional desktop input devices such as keyboards and mice cannot be used, and so new user interfaces are required. Thomas et al. performed a survey of various input devices for wearable computers and how they could be used for collaboration tasks (Thomas et al., 1998). Some currently available devices include chord-based keyboards, forearm-mounted keyboards, track-ball and touch-pad mouse devices, gyroscopic and joystick-based mouse devices, gesture detection of hand motions, vision tracking of hands or other features, and voice recognition.

The first demonstration of AR operating in an outdoor environment was the Touring Machine by Feiner et al. (1997) from Columbia University. The system is based on a large backpack computer system with all the equipment necessary to support AR attached. The Touring Machine provides users with labels that float over buildings, indicating the location of various buildings and features at the Columbia campus. Interaction with the system is via a GPS and
head compass to control the view of the world, and when gazing at objects of interest longer than a set dwell-time the system presents further information. Further interaction with the system is provided by a tablet computer with a web-based browser interface to provide extra information. The Touring Machine was then extended by Höllerer et al. (1999) for the placement of what they termed Situated Documentaries. This system is able to show 3D building models overlaying the physical world, giving users the ability to see buildings that no longer exist on the Columbia University campus.

The Naval Research Laboratory is investigating outdoor AR with a system referred to as the Battlefield Augmented Reality System (BARS), a descendent of the previously described Touring Machine. Julier et al. (2000) describe the BARS system and how it is planned for use by soldiers in combat environments. In these environments, there are large quantities of information available (such as goals, waypoints, and enemy locations) but presenting all of this to the soldier could become overwhelming and confusing. Using information filters, Julier et al. demonstrated examples where only information of specific relevance to the user at the time is shown. This filtering is based on the user’s current goals, and their current position and orientation in the physical world. The BARS system has also been extended to perform some simple outdoor modelling work (Baillot et al., 2001). For the user interface, a gyroscopic mouse is used to manipulate a 2D cursor and to interact with standard 2D desktop widgets.

Apart from the previously mentioned systems, a small number of other mobile AR systems have also been developed. Billinghurst et al. (1998; 1999) performed studies on the use of wearable computers for mobile collaboration tasks. Yang et al. (1999) developed an AR tourist assistant with a multimodal interface using speech and gesture inputs. The TOWNWEAR system by Satoh et al. (2001) demonstrated high precision AR registration using a fibre optic gyroscope.

3. The Tinmith System

The Tinmith system is an outdoor augmented reality wearable computer system, and we have produced a number of demonstration applications (Piekarski and Thomas, 2003a, b). These applications use a glove-based menu system, image-plane manipulation techniques, and a new model creation methodology called ‘construction at a distance.’ This novel method allows users to construct 3D models of remote objects by walking around the object, but without actually touching it or being close to it – the only requirement is that it is visible. The Tinmith system forms the base on which we wish to investigate mobile through-walls collaboration systems.
The Tinmith backpack, as of 2006, is lighter and more robust than our previous systems. We have taken our eight years of experience in the field and built a system using the best components that are currently available and have designed our own custom housing to make the system robust for use in outdoor conditions. The whole system weighs 4 kg. Battery packs are an additional weight of approximately 2–4 kg depending on operating time and battery technology used. The profile of the system is almost to the point where a large jacket can be worn over the top that would conceal the system. The photos in Figure 3 show the left side (with ventilation fan and power switch), and the right side (with antennas and helmet connector).

![Figure 3. New Tinmith backpack.](image)

The images in Figure 4 show the complete system from the front and rear with the all components visible. Note the lack of complex cables and the compact size of the unit. The batteries on the front are hot-swappable during operation, and two 8,000 mAh Ni-MH batteries are used for 3 h of operation.

![Figure 4. Full system.](image)
The entire system can automatically start doing AR visualisation within 70 s of turning on the power switch. Figure 5 depicts the Tinmith Gloves that are the main input devices for the user interface. This is composed of a set of pinch gloves for menu selection and thumb tracking to control two different cursors (one for each thumb).

Figure 5. The Tinmith gloves.

The system contains a custom modified Pentium-M 2.0 GHz computer with Nvidia GeForce 6600 graphics. The processor is designed for mobile applications, and the graphics processor is capable of handling any complex rendering task with ease. We use sub-50 cm accurate GPS receivers to provide excellent position tracking outdoors, and an InterSense 3 cube for orientation sensing. The system also implements 802.11 for wireless networking, Bluetooth for wireless peripherals, wireless video output, and USB and VGA ports for debugging.

The Wearable Computer Lab of the University of South Australia has shown that augmented reality can be used to visualise architectural designs in an outdoor environment (Thomas et al., 1999). A design of an extension of the Physics building on the Mawson Lakes campus of the University of South Australia was effectively represented with the Tinmith mobile augmented reality platform. As an illustration of gaining the sense of a design, the straightforward extension was designed with a height of only 3 m. Informal testing showed this design flaw immediately. Even with simple line drawings for the building from the 1999 system (see Figure 6), a general feeling of shape and size was portrayed to the user.

The current Tinmith system provides full 3D rendering of architectural designs. The Wearable Computer Laboratory contracted a local graphic artist to build a small town to allow us to experiment with laying out a large collection of buildings and houses. Although these models are not from a traditional CAD system, they allow us to investigate the ability to visualise a small town.
Figure 6. Tinmith architecture visualisation circa 1999.

Figure 7 depicts a house and car. A user is able to walk up to and around the house to gain a feeling of the size and shape. Figure 8 shows the ability to display finer detail as in the veranda on the side of a house. Figure 9 demonstrates the ability to visualise a street scene. The cars on the street are animated and are programmed to drive in a looping pattern along the streets. The scaling of the building appears to be incorrect in relation to the physical building. This is not the case, but it demonstrates a limitation of the system: correct occlusion must be performed. The physical building shown in the image was not defined in the town model, and the virtual buildings are in fact behind this physical building. Because the virtual buildings are much farther away, the proper perspective scale shows them much smaller. The current Tinmith system renders all graphical images on top of the video stream. If the system does not
know to occlude a graphical object, they will always be drawn on top of whatever physical object is being viewed. This can be avoided if models of the physical objects are incorporated into the graphical scene.

The Wearable Computer Laboratory has been investigating through-walls collaboration techniques. In particular they have developed a new interaction metaphor they have termed god-like interaction, or _Hand of God_ (Stafford _et al._, 2006). This metaphor was developed to improve collaboration between a user located outdoors using mobile augmented reality systems, and a user located indoor working on tabletop projected displays. The metaphor leverages an indoors user’s ability to manipulate physical props as well as their hands onto a table surface that is then scanned as a 3D object and transmitted.
wirelessly to a remote user outdoors. Small objects such as models of buildings and houses can be placed on a map, Figure 10, and will be converted into 3D textured models. These 3D models are then sent as geo-referenced to the outside user who is then able to view them in the specific orientation and position in the physical world, Figure 11.

**Figure 10.** Operation of the Hand of God.

**Figure 11.** View from the HMD of the outside user.
4. Using a Mobile Augmented Reality Platform

The Wearable Computer Laboratory is investigating and developing computer technology that literally takes computers out into the field, where computer applications are geographically aware and designed to interact with users in their world, not just in the confines of the computer’s artificial reality (Piekarski and Thomas, 2003a).

By providing information in a 3D form, in scale with the surroundings, AR systems provide significant benefits:

- Physical objects with known locations can be found more rapidly, especially in featureless terrain, thus saving time and costs. Imagine you are at a large building site with many services level to the ground, and you wish to locate a number of them. AR visual cues can be provided to make these objects easier to locate.
- In the case of an object being underground, the location of this object can be determined within the accuracy of GPS and orientation sensor systems. Locating underground pipes is a good example of how this could be employed.
- Previously invisible features, such as boundaries, become visible without the use of physical markers. In the case of a housing development, this would help with locating and understand the different lots.
- Overlaying more than one information source allows the relationship between objects to be determined easily. In the above housing development example, information such as owners, prices, proposed house structures, and tax information could display in such a way as to make it easy to understand the relationship between the different lots. Being able to perform this assessment in-situ with the physical surroundings would help users with particular decision-making processes. Potential buyers would be able to make decisions that are more informed.
- Features can be viewed from orientations that are more appropriate to the task than a map or drawing may allow. Maps and drawings are inherently 2D while the physical world is 3D. Viewing a new house from the first person perspective in-situ provides additional information and context, and makes issues such as size, shape, and colour easier to understand.

5. The Role of a Mobile Architectural Visualisation System in the Design Process

As an illustration, a number of architects and I discussed the possibilities of using outdoor augmented reality for the visualisation of architectural designs. The Wearable Computer Lab had made a number of simple building models of extensions to one of the buildings on our campus. One of the extensions was a large two-storey room off the end of a lecture theatre. The building model was developed in AutoCAD, and the existing building was based on drawings obtained from the University of South Australia. I explained how a fire escape
was not on the drawings. Our extension was to be built right on top of this fire escape staircase. This became pointedly obvious the first time we viewed our model of the extension with the Tinmith system. I remarked to the architects, “Of course you guys would never make such a mistake.” They all laughed and stated that these sorts of mistakes do happen, and being able to catch them early would be of great benefit.

As illustrated, a major benefit of an outdoor augmented reality system such as the Tinmith system is that it helps people visualise architectural designs in their physical outdoor context. The Tinmith system is designed to meet the following objectives for such visualisations:

- Architectural designs should originate from standard CAD packages and be stored in standard interchange file formats.
- Architectural designs will be displayed relative to their physical site placement.
- Modifications can be made at the building site.
- The user interface must be easy and intuitive to use.

Such outdoor augmented reality systems are required to be consistent with two contemporary architectural design methodologies. The first is that the system must be able to import data from standard architectural design software packages. The heart of the system is the facility to visualise or see characteristics of the architectural design in the field, imparting to the user a feeling of how the architectural artefact will fill or change the physical space. The targeted end users of such a system are architects, engineers, designers, and clients.

An outdoor augmented reality system could be employed at a number of key points in the design and construction process:

- **Scoping the project:** When an architectural project first starts, some initial ideas can be quickly examined in-situ to understand the direction of the building better. Physical walkthroughs may be performed in any large flat area such as a parking lot or playing field (Thomas and Piekarski, 2003).

- **Team collaboration:** In many cases, numerous people are involved in the decision making process at the site where a building will be constructed. Augmented reality allows for a common visualisation of the design or engineering concepts for all parties. In these cases, an HMD might not be the appropriate display technology, and the Wearable Computer Laboratory has been experimenting with a tripod-mounted augmented reality display. An experimental system for visualising GIS data has been built (King et al., 2005).

- **Determine the proper placement of the building:** A key feature of augmented reality is the ability to quickly visualise and convey understanding of virtual information in the context of the physical world. A clear example of this is the placement of a potential structure on a building site, which enables the user to understand the issues of where this structure will be located, potential problems, alignment with other structures or features, and to form a better understanding of the size and shape of the structure. The placement of the virtual building
allows a better understanding of the current shape and gradient of the building surface giving an insight into how the building surface needs to be reshaped.

- **Visualising conceptual designs in-situ:** The relationship of a house or building to its surroundings is critical for the overall design. The ability to visualise these structures in-situ with other buildings, vegetation, and landscape can greatly improve the overall outcome of the design. Current use of digital enhanced imagery is limited. There is only one viewpoint per image, and these images poorly portray the overall combination of these in-situ features. Multiple designs may be presented to the customer while on site. This enables the end-user to make more informed design choices.

- **Making modifications on site:** As the visualisation is performed on a computing system, design modifications and annotations may be applied on the building site. Decisions can be recorded and tagged to the relevant portions of the electronic design. Changes to paint colour and building materials easily be reviewed and recorded. In the early stages of the design, primary exterior 3D designs can be presented with the expectation of quick modifications. For example, structural parameters such as building heights can be adjusted with some simple editing. One architect I am currently working with performs early designs on Google SketchUp\(^1\) as this system provides him with a method for quick end design for early discussions with clients. He stated that current CAD systems require too much effort for such quick designs. These designs can be exported to Google Earth\(^2\) enabling the architect to place the design in the correct location quickly. The augmented reality system can access the Google Earth data and display this to the client.

- **Visualising construction and engineering data on site:** In addition to architectural design information, construction and engineering, data may also be viewed via the augmented reality system on site. This design data is in a similar format to that of architectural designs. During the construction phase, this data may be viewed via augmented reality for the following reasons: review of progress with client, location-based technical details for an engineer or contractor, and planning for the next phase of the operation. The case of a team of engineers and architects discussing critical issues, the ability to view the designs with the current state of construction will enable a clearer understanding. This would hold especially true for the visualisation of key structures to be built at major milestones.

### 6. Conclusion

In conclusion, this chapter presented an overview of how augmented reality can improve the visualisation of architectural designs. An overview of wearable computer technologies and augmented reality was provided for a better understanding of the technology. The Wearable Computer Laboratory’s Tinmith

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2. Google Earth [http://earth.google.com](http://earth.google.com)
wearable outdoor augmented reality backpack system was described to demonstrate the current state of the art in this form of technology and the following six key points in the design and construction process were detailed as areas in which this technology might be applied:

- Scoping the project
- Team collaboration
- Determine proper placement of the building
- Visualising conceptual designs in-situ
- Making modifications on site, and
- Visualising construction and engineering data on site

The key contribution of the chapter is a description of how the user of a wearable computer augmented reality system can facilitate the architectural design process in the areas elaborated showing the vast potential awaiting application.

**Acknowledgements**

I wish to acknowledge the members of the Wearable Computer Laboratory for creating and developing the Tinmith system. Dr. Wayne Piekarski led the Tinmith system project, and other key contributors are as follows: Ben Avery, Ross Smith, Ben Close, and Gary King.