AGENT-BASED AUGMENTED REALITY SYSTEM FOR URBAN DESIGN: FRAMEWORK AND EXPERIMENTATION

XIANGYU WANG
Lecturer, Key Centre of Design Computing and Cognition,
Faculty of Architecture, University of Sydney
Sydney NSW 2006, Australia
Email address: x.wang@arch.usyd.edu.au

Abstract. Urban design is traditionally regarded as a highly collaborative activity and its costly nature dictates that errors and oversights could easily induce budget overflow and time waste. Augmented Reality (AR) technology, the addition of virtual entities into the real world view, once complemented by the versatile nature of embodied intelligent agents, is envisaged to be promising for supporting design assessment and collaboration within design team. The paper presents a visualization and simulation framework for an intelligent agent-based AR system, called Augmented Reality-based Urban Designer (*ARUDesigner*), which could allow designers to assess virtual urban designs in a real and familiar workspace. The paper also presents the initial prototype of *ARUDesigner* and the experimental evaluation results from a pilot study.

1. Introduction

Urban design is traditionally regarded as a highly collaborative activity and often involves group of people working together as a team. The costly nature of urban design means that errors and oversights could easily lead to budget overflow and time waste. However, effective collaboration could be difficult to achieve without an appropriate common visualization platform. Augmented Reality (AR) is a promising visualization platform for further exploration into collaborative systems, where designers can be plunged into a real environment to interact with virtual information. AR could allow urban design scenarios to be assessed from different perspectives that would otherwise be impossible and inefficient for traditional methods.

Augmented Reality has been exploited to support architectural or urban design (Aliakseyeu, 2002; Ben-Joseph et al., 2002; Kieferle and Wossner, 2003; Piekarski, 2003). What distinguishes the work in this paper from those is the combination of augmentation concepts (Augmented Reality, intelligent agents, tangible interface) into one collaborative tool for urban designers — Augmented Reality-based Urban Designer (*ARUDesigner*). The visualization and simulation framework for *ARUDesigner* is developed, which could allow designers to assess design issues in a real and familiar workspace. This paper also presents the implementation of an initial prototype of *ARUDesigner* and experimental evaluation from a pilot study.

2. The Framework of ARUDesigner

The *ARUDesigner* framework could allow designers to interactively manipulate objects in a proposed virtual urban area and assess the environmental effects from design changes through agent-based simulation. The system setup of *ARUDesigner* is conceptually depicted in Figure 1. Designers will be able to sit around the physical meeting table and see a virtual urban design overlaid onto the table through their head-mounted displays (HMDs). The entire framework consists of *visualization, simulation,* and *interaction* layers, as illustrated in Figure 2 and discussed in the following sections.

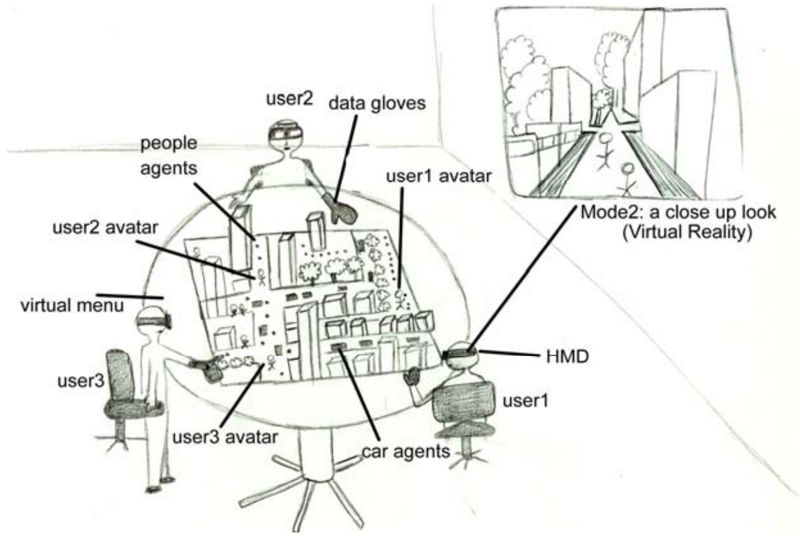


Figure 1. Conceptual setup of *ARUDesigner*

2.1. VISUALIZATION LAYER

The entire system architecture of visualization layer is depicted in the upper cell of Figure 2 and major components are explained in this section.

2.1.1. Rendering Hardware

Computing unit: A cluster of networked CPUs could make the system overall performance viable for multi-users real-time interactions. Changes to the virtual urban design made by individual designer would be constantly relayed to the central server where they would be sent to all designers for scene updates and synchronization in a real-time manner.

Data gloves: Interactions with *ARUDesigner* is via data gloves, which provide a tactile and intuitive interface for manipulating virtual objects. Data gloves could be used to navigate an interactive virtual menu which allows access to the design database. Designers could ‘drag’ structures from database via menu onto the proposed urban design area, configuring their parameters such as location, size, and orientation. They could then be tweaked either directly or through an attribute menu for precise control on those parameters.

Tracker: An effective method of achieving accurate tracking in *ARUDesigner* is to use radio-frequency (RF) tracking chips combined with vision-based tracker (ARToolkit, 2006).

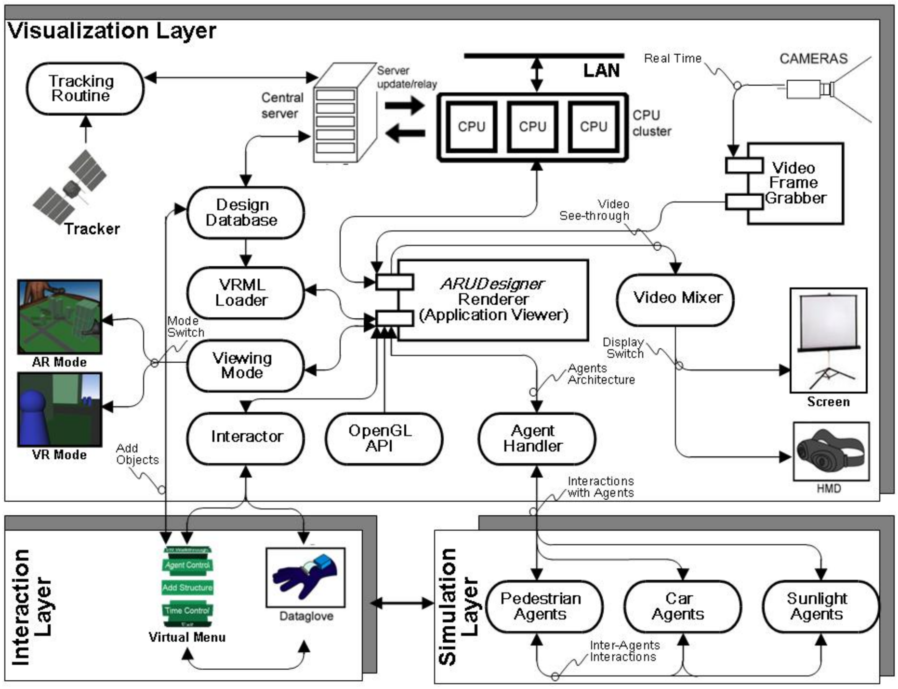


Figure 2. System Architecture of *ARUDesigner*

2.1.2. Dual Viewing Mode

The visualization layer also incorporates AR/VR dual viewing modes as shown in Figure 2. Such dual modes could increase designers' awareness by providing them with multiple views of the design area rather than limiting them to a particular perspective.

Augmented Reality (AR) mode: The AR mode superimposes 3D visualizations of structures within an urban area onto the top of the meeting table where the mixed scene could be viewed through HMDs. With a bird-view in such tabletop overview mode, designers are able to see the entire virtual urban design together with all the agents present in the design.

Virtual Reality (VR) mode: *ARUDesigner* allows users to switch to the VR mode where an immersive first-person walking-through experience can be enabled by fixing one's view onto a selected agent's view in the virtual design. Following an agent's navigation could allow one to experience the feedback from an entirely new perspective and might facilitate the identification of design issues and development of corresponding solutions.

The dual nature of the viewing mode limits the types of displays that could be used in *ARUDesigner*, as the VR walking-through mode requires complete immersion of the user (completely restricting their views of the surrounding environment), whereas the AR mode requires the combination of virtual objects with the one's real space. As a result, a combination of projector (for AR mode) and head-mounted displays (for VR mode) might be suitable to accommodate these two different viewing modes.

2.2. SIMULATION LAYER

Once the initial urban design is developed at the first stage through the visualization layer, designers could place intelligent agents into the virtual area to simulate movement of actors represented by virtual avatars in *ARUDesigner*. Behaviours of these avatars are governed by an agent architecture that can effectively sense the real and virtual worlds. Designers could assess the effects which any design change imposes on issues such as congestions.

2.2.1. Categories of Agents

Agents are classified into three major categories: pedestrian, traffic, and sunlight (see the lower right cell in Figure 2).

Pedestrian agents: simulating a pedestrian's way-finding experience could calculate the shortest route to a target building. The behaviours of the agent could be defined so that the virtual pedestrian proceeds along this route at a defined speed using only footpaths to travel where possible, and stops at roads, waiting for a break in traffic before proceeding further. Designers could also modify this behaviour so that instead of the shortest route, the pedestrian follows the route that requires the fewest roads to be crossed in a specified area.

Traffic agents: A car agent, for example, might be required to respond to the speed-limit parameter of the road on which it is driving, or to the level of pedestrian traffic.

Sunlight agents: Virtual sunlight could be placed at any position in the virtual sky to simulate the intensity and speed in different times of the day and the year. Sunlight simulation could enable designers to assess the effects of a new building on the light exposure of surrounding existing buildings at various times throughout the day. For example, designers could assess whether the shadows cast by a certain building would have a negative impact on the surrounding buildings or parks, or where to position a new building to maximize its sunlight exposure.

2.2.2. Interactions with and between agents

Agents could be programmed with specific behaviours to enable them to generate useful information for designers. Designers can run the simulation, evaluate the results, modify agent behaviours, and re-run the simulation. Designers could also modify the agent's behaviours either at the time of spawning, or in the middle of simulation. This would allow instantaneous comparison of the modified behaviour with the original behaviour.

In addition to fixed buildings, agents should also be responsive to their surrounding agents to the extent required by their pre-defined behaviours. Proximity to certain agents would provoke responses. For instance, cars would be required to slow down when within a certain distance of a bicycle and visible congestion as a result of this might lead designers to add a bicycle lane to the congested area. Urban design could be progressively improved so that urban problems experienced by different groups of agents are minimized and balanced.

2.3. INTERACTION LAYER

The majority of functions are accessed via the pop-up interactive virtual menu (see the lower left cell in Figure 2). The menu could be triggered by the designer via data glove. Once the menu is selected, designers can cycle through the options by rotating fingers or hand in a circular motion. The menu would rotate in response to the rotation of the user's hand allowing quick access to all the functions. The list of functions would change according to the context in which the menu is used. Switch between the AR and VR modes could be realized by the context menu. In the AR mode the designer could select and move virtual objects using their data glove. Touching a virtual building with an out-stretched finger will select it and it can also be 'grabbed' just as with a physical object. If a specific object is selected for details, another detailing menu is active for higher level parameters viewing and setting.

In the VR mode, tilting the hand could control the rotation to the left or right and pitching the hand up or down could allow designers to look up and down. Clenching a fist could make designers move forwards in the virtual world (increasing their velocity) while opening the hand completely could reduce their velocity. Backwards motion would be the result of a negative velocity. Holding the hand in resting position could reduce the velocity to zero. The views displayed in the HMDs of all the other passive designers could also be synchronized with the first-person perspective of a discussion-leading designer, which creates a common context (e.g., spatial frame of reference) for discussion.

3. Initial Prototype Implementation and Experimentation

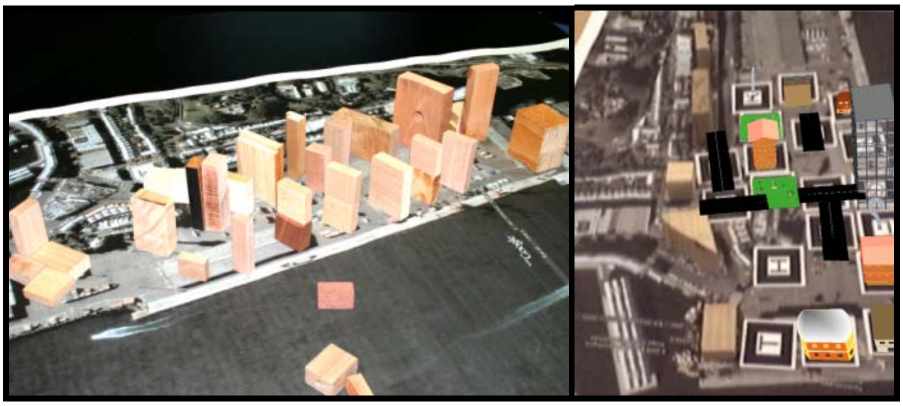
The visualization layer is the primary one in the framework of *ARUDesigner*, therefore, the initial prototype focused on the realization of the visualization layer (see Figure 3 for testbed setup).

Figure 3. Setup of experimental testbed

The objective of the pilot study presented in this section is to identify the strength/weakness of the current *ARUDesigner* in supporting collaborative urban design. Lessons learned could improve *ARUDesigner* and facilitate smooth integration of the visualization layer with the simulation and interaction layers.

3.1. EXPERIMENT PROCEDURE AND METHOD

There are totally four groups recruited for the experiment: two with architecture background and two without. Each group has two members for collaboration. The hypothesis is that subjects with architecture background should perform better. Traditional wooden block (TWB) method (see Figure 4a) was chosen as the benchmark for validation of ARUDesigner (see Figure 4b). All groups were allowed a specific timeframe to use two methods on two different design scenarios respectively. The first scenario is to construct a layout play at Millers Point in Sydney that focuses on re-establishing new residential area (75%) in mixture with commercial district (25%). The second scenario is to design a layout plan that seeks to transform Millers Point into a new commercial area (75%) with public services (25%) in order to attract foreigners and tourists. Methods and scenarios were mixed for the four groups to minimize the effects of scenario difference.



(a) (b)

Figure 4. (a) Traditional wood block (TWB) method; (b) Augmented scene in *ARUDesigner*

All the virtual objects used in *ARUDesigner* were modeled in ArchiCAD and the quality is acceptable. There are totally 14 design objectives which were exemplified from realistic urban design scenarios and practice (see TABLE 1). Subjects were asked to accomplish those design objectives as many as possible within a 10-minute time window. To measure the effectiveness of *ARUDesigner*, the number of accomplished design objectives by each group using the two methods was documented.

Additional questionnaire was administered as a subjective feedback methodology and video recording was used as an objective analysis where the analysis focused on the de-facto behaviour of the subjects (e.g. movement, gesture and oral communication).

TABLE 1. List of design objectives used in the pilot study

Design Objectives	Design Objectives
[1] Provide points of interest for the pedestrians and tourists.	[9] Provide easy-access to public parking
[2] Allow point of interest be easy to find.	[10] Provide traffic control that allows efficient traffic flow in peak hours while assuring pedestrians' safety
[3] To promote character in townscape and landscape, by responding to and reinforcing locally distinctive patterns of development, landscape and culture.	[11] Promote accessibility and local permeability by making places that connect with each other and are easy to move through.
[4] Construct a logical transport network for the resident/local services.	[12] Provide legibility through developing recognizable routes, intersections and landmarks that help people find way
[5] Optimise the use of land and space for residential (or commercial) purposes.	[13] Ensure the privacy and security for local residence.
[6] Make efficient usage of natural lighting	[14] Provide adaptability through development that allows future change/redevelopment for social, technological and economic conditions.
[7] Establish a layout design that make useful of any existing resource from its surrounding.	
[8] Allow the public to enjoy the waterfront scenery while ensuring the safety.	

3.2. ANALYSIS AND DISCUSSION

The design objective achievements within 10-minute window for the two methods by the four groups are summarized in TABLE 2. It is noted that regardless the method, the group 3 and 4 achieved more objectives than the group 1 and 2, which conforms to the assumption that subjects with architecture background should perform better due to their established familiarity with design objectives in urban design. There is only marginally difference in performance by the two non-architecture group for the comparison of the two methods. The slightly lower performance by *ARUDesigner* might result from usability issues in the current initial prototype. For example, the groups spent a portion of the time in re-adjusting the tracking markers in order for the virtual models to appear properly on the screen. One of the apparent advantages of TWB is the design model control. It was easy for subjects to access the models since their eyes and hands can manipulate naturally without trouble. In contrast, model control was much harder since the subjects manipulated the markers and then had to move their sights from the markers on the table onto the screen to receive feedbacks when they were using *ARUDesigner*. Most subjects reflected that model control should be improved for *ARUDesigner*, in order to make it a better tool than TWB. Furthermore, *ARUDesigner* also made subjects much harder to communicate with other team members since they had to move their eye-sights around to see the model.

TABLE 2. Comparison of number of design objectives accomplished by the four groups using TWB and *ARUDesigner*

	TWB	*ARUDesigner*
Group 1	7	6
Group 2	7	6
Group 3(Arch)	13	10
Group 4 (Arch)	9	9

The group 3 accomplished 13 objectives by TWB and 10 using *ARUDesigner* as compared with even numbers for group 4. The reason is that the group 3 received less training for using *ARUDesigner*. Thus, participants had to spend more time to associate each tracking marker with the represented model. *ARUDesigner* could help to improve the efficiency of design activities if more training time is allowed to familiarize the users with what each marker represents. In summary, *ARUDesigner* could be easier in getting ideas across although it could also slow down the entire process due to certain usability issues.

More results are revealed if the accomplished design objectives are closely examined. For instance, all the groups could construct a logical transport network for the resident/local services and 75% participants did the task of optimizing the use of land and space for residential (or commercial) purposes when they used TWB. In comparison with using *ARUDesigner*, the result has shown exactly the same as TWB. Therefore, both methods are effective to be used in arrangements for the transportation and area separation with optimism in urban design. On the other hand, it seems that all subjects could use *ARUDesigner* to provide points of interest for the pedestrians and tourists and allow point of interest be easy to find. In addition, 75% groups could promote character in townscape and landscape, by responding to and reinforcing locally distinctive patterns of development, landscape and culture when they used *ARUDesigner*.

4. Conclusions and Future Work

This paper presents a visualization and simulation framework for the Augmented Reality-based Urban Designer (*ARUDesigner)* system which could allow designers to assess design solutions in a real and familiar workspace. This paper also presents an initial prototype implementation of *ARUDesigner* and the evaluation results from a pilot study. The results show that although some technical difficulties in *ARUDesigner* introduced negative performance factors on the outcome, all the subjects believed that the system holds significant potentials in urban design. Future works are to prototype the simulation and interaction layers, and integrate them with the current *ARUDesigner* prototype.

References

Aliakseyeu, D., Martens, J., and Rauterberg, M.: 2006, A computer support tool for the early stages of architectural design, *Interacting with Computers*, **18**(4), 507-868.

ARToolkit: 2006, http://www.hitl.washington.edu/artoolkit/

Ben-Joseph, E., Chak, D., Ishii, H., Kangi, Z., Piper, B., Underkoffler, J., Yeung, L.: 2002, Augmented urban planning workbench: overlaying drawings, physical models and digital simulation, *ISMAR 2002*, pp. 203-211.

Kieferl, J. and Wossner, U.: 2003, Mixed Realities: Improving the planning process by using augmented and virtual reality, *the 4th Conference on new technologies in landscape architecture 2003*, Dessau.

Piekarski, W.: 2003, Backpacking scientist rearranges the world using augmented reality. URL: http://www.sciencenow.org.au/sciencenow/2003/wayne_piekarksi.htm