Interactive Space Generation through Play

Exploring Form Creation and the Role of Simulation on the Design Table

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In this paper we report on recent developments in ARTHUR: an approach to support complex design and planning decisions for architects together with the simulation of pedestrian movement and the integration of existing CAD tools on the design table. Following a brief introduction, past and current work that has taken a similar approach will be reviewed. Next we describe a scenario that integrates agent-based simulations of pedestrian movement with space creation, and then give an overview of the system before finally discussing findings related to recent user evaluation studies of the system. This paper suggests that the integration of simulated pedestrian movement on the design table, while going through a cycle of reflection-in-action, plays a vital role in exploring possible design solutions and encourages new and different ways of thinking about design problems.

Keywords: *Tangible user interface, pedestrian simulation, collaboration, Augmented Reality (AR), CAD integration.*

1. Introduction

The use of computers in design can be traced over at least three decades. Developments in user interfaces have evolved from the early command line interfaces, where geometry was usually created and manipulated by typing commands, towards the current user interfaces with the ability to manipulate graphical representations of objects on the screen with the mouse interactively through direct manipulation. One of the earliest examples of an application using direct manipulation operations is "Sketchpad" by Ivan Sutherland. This was the first Graphical User Interface (GUI), long before the term was coined. However, for a number of reasons many earlier expectations that computers might fundamentally change the ways we design did not come to realization and the common perception of the application of CAD to architectural design is still associated with drafting and modelling (Peng, 2001).

However, we can see that developments in computing for architectural design since the 90s follow a number of main lines: Virtual Reality (VR) represents one development, which, for a number of reasons, has continued to be of an academic rather than practical interest (Penn et al, 2004). In the last decade a new research wave has emerged linking the digital and the physical worlds. This has led to the identification of a number of key research areas; one of these is Augmented Reality (AR) with its capability of augmenting the physical world with digital information, which may help change the current approach to the design process. Additionally, a number of interfaces were introduced as an attempt to explore the relation between the digital information and the physical representation (Ulmer and Ishii, 2001). It appears that the use of the computer in architectural design is currently facing the challenge of getting past the 'WIMP (window, icon, menu, pointing devices) plateau', introducing new techniques that take advantage of the capabilities of today's computing systems and more effectively matching human capabilities (Hinckley, 1997). AR spatial interaction techniques form one possible candidate for the post-WIMP interface. Moreover, CAD needs to support critical dialogues between design ideas and their expressions. This was recognized by Donald Schon (1983), who proposed a theory of reflection-in-action acting as a framework for design learning and teaching based on his analysis of design dialogue between an architecture student and a studio master. One way of achieving this is by integrating simulation techniques such as pedestrian movement analysis into the design process, which could be seen as the binding link in the dialogue while going through a cycle of reflection-in-action. This was supported by our recent observations of designers collaborating while interacting with a digital environment, which suggests that the new AR medium seems to hold out a prospect for quite different ways of working and may lead to new forms of genuinely collaborative form generation (Penn et al, 2004).

In this paper we present recent developments in ARTHUR, our approach to an AR system supporting collaborative architectural design and urban planning. We have previously illustrated elsewhere early results of the user evaluation of this system.
Here we report on findings related to recent tests with the pedestrian simulation on the design table. Moreover, preliminary feedback related to the early stage of CAD integration is described.

2. Related Work

Over the past few years there have been several attempts to apply AR systems in the area of architectural design and urban planning. One of the early examples provided users with an "X-ray vision" inside a building, by visualizing the hidden elements of a building (Webster et al, 1996; Feiner et al, 1996). Other AR systems supported the assembly of complex systems, for instance, Augmented Reality for Construction (Feiner et al, 1995), for the construction of space frames by indicating the position of each structural element in space. Dias et al (2002) developed MIXDesign, a Mixed-Reality system oriented towards architectural design, limited to basic manipulation of imported geometry and using tangible interfaces with AR Toolkit patterns and paddle gestures.
More recent AR systems for collaborative design and planning (described in detail in Penn et al, 2004) provide common view and collaborative manipulation of complex spatial problems and support the spatial composition of complex buildings - compare BUILD-IT and Tiles. They integrate planning rules - compare AR Planning Tool - and use sophisticated interaction metaphors with advanced concepts for integrating physical and digital workspaces - compare Luminous Table and ARVIKA (Broll et al, 2004). An approach that goes beyond this is the support of collaborative architectural design and urban planning meetings through 3-dimensional computational simulation. This approach is applied in a number of current and recent research projects:

URP (Underkoffler & Ishii, 1999) is an early prototype for collaborative urban planning. The infrastructure allows digitally augmented tagged physical models placed on a projected table surface to cast shadows accurate for any time of day, and to throw reflections off glass facade surfaces and visualise a simple 2D Computational Fluid Dynamics (CFD) analysis of wind flow.

The Luminous Table (Ishii et al, 2002) developed by the Tangible Media Group integrates sketches, physical models, and computational simulations into a single workspace. Physical objects are tracked with cameras. 2D drawings and 3D physical models are augmented with a 2D video projection to simulate sunlight shadows, wind patterns and traffic.

Illuminating Clay (Piper et al, 2002) supports real-time computational analysis of landscape models. Users change the topography of a physical clay model while the changing geometry is captured in real-time by a ceiling-mounted laser scanner. The results of the analysis are projected back into the workspace and registered with the surfaces of the model.

Digital Sandbox (Yi-Luen Do, 2002) is a single user system that provides designers with the ability to manipulate a digital landscape using hand gestures. It uses image processing of hand gestures from two video cameras to infer the landform sculpting actions and simulates storm water accumulation over the digital terrain. The interaction and the simulations are projected on a vertical projection screen.

MouseHaus Table (Huang et al, 2003) is a physical interface for urban pedestrian movement simulation in a group setting. The portable interface includes a video camera, colored paper, scissors, and a table with a projected display. The physical interface is driven by an image processing program to capture and analyze the images. With a registration process, users can employ color paper cutouts to represent building type, size, and location as input for the pedestrian movement simulation program.

Create (Loscos et al, 2003) developes a mixed reality framework enabling real-time construction and manipulation of virtual objects using immersive stereo displays and a wide projection screen (CAVE like environment). The aim is to provide the user with interaction within highly realistic environments including real time vehicle and crowd simulation.

We present our approach ARTHUR, which integrates form creation with the simulation of functional performance, such as the simulation of pedestrian movement, as an important component of the collaborative design table. ARTHUR uses optical augmentation and wireless computer-vision (CV) based trackers to support collaboration within the 3D environment (Figure 1). Computer Vision techniques take input from stereo Head-Mounted Cameras (HMCs) and a fixed camera, to track the movements of placeholders on the table and the user's hand gestures. Virtual objects are displayed using stereoscopic visualization to seamlessly integrate them into the physical environment. Moreover, and unlike most AR systems, complex geometry can be directly created within ARTHUR using the integrated CAD system (MicroStation), which supports more advanced functionality such as 3D sketching and complex solid modelling.

Figure 1
Collaboration within the ARTHUR environment.

3. Designing with real time movement simulation

Scenario

A design session consists of two people seated around the design table wearing lightweight augmented reality displays. Cameras, one on each side of the display, track the scene. On the table there are placeholder objects and pointing devices for use in interaction with the virtual media. A 3D virtual model appears through the display with four static blocks. Four additional walls are attached to the placeholder objects (PHO), and thus can be moved by moving the placeholder objects. A specified number of agents appear on the table from two virtual blocks (representing the underground stations - UG); these use vision to assess the spatial configuration, and move towards the open space. The designers discuss the configuration and reorganise the walls by moving the PHO. The agents start to explore the area around, reproducing the movement patterns of real pedestrians in the area. The two designers observe the scene for a while and decide to move one of the walls to achieve a better flow to the central part of the space. Consequently games are played by moving the walls to affect movement patterns while going through a cycle of reflection-in-action with the simulated agents to investigate possible design solutions on the design table. After observing the new pattern of movement, reproduced through the agents' movement and mapped on a 2D screen in a form of traces, they decide to select the solution that provides good accessibility to the central parts of the design and stop the simulation. This is the ARTHUR concept (Broll, Störring et al, 2003), with the attempt to integrate the simulation of pedestrian movement as a critical component on the collaborative design table.

4. The System Overview

The ARTHUR system is an Augmented Reality (AR) based environment to support the collaboration of architects and other users at architectural design, urban planning and review sessions. It uses AR to project virtual objects on top of a real round table by enhancing the real meeting situation with live 3D information. Stereoscopic 3D projection classes (head mounted displays – HMDs) are used to project the 3D information in the working environment of the users, integrating those seamlessly into their natural surrounding. In order to interact with these 3D objects several new interface mechanisms are provided. Users may use placeholder items on the table as tangible interfaces for virtual objects, grab a 3D pointing device (wand) or even use their fingers for gestures to be interpreted by the system. In the following we give a short overview of the ARTHUR system. The individual system components are described in detail in (Penn et al, 2004).
The ARTHUR system consists of four main components:

1. The head-mounted displays (HMD) provide a high-resolution image of the (3D) virtual objects, superimposing the real environment of the user using an optical see-through mechanism. Thus in

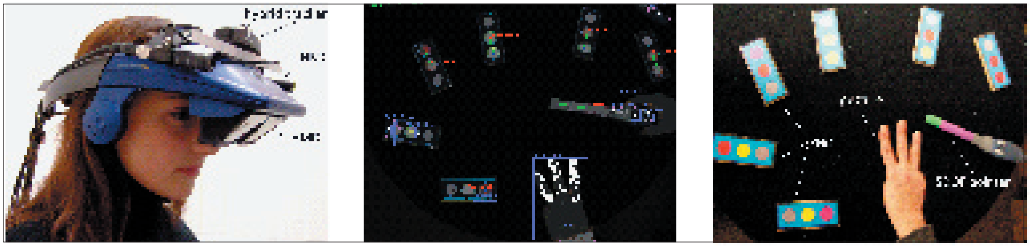

Figure 2
ARTHUR See-through HMD and CV-based recognition of PHOs, pointers, and finger gestures.

contrast to Virtual Reality (VR) displays, the user is always part of his or her natural environment, fully aware of any real events (Figure 2. left).

2. The user interface mechanisms described are realized using computer vision (CV) techniques. Cameras mounted on the HMDs or above the round table recognize movements of placeholder items or wands and recognize user gestures (Figure 2).
3. An AR framework supports the connection and communication of all these devices and links them to the actual architectural design, urban planning and simulation applications by an application interface. The framework supports multiple users, ensuring that all participating users see identical virtual objects on the table.
4. A graphical user interface definition environment (GRAIL) allowing experienced users to configure and adapt the user interface of the AR environment. Thus the users may specify how to manipulate (for instance scale, move or restructure) virtual objects using the interaction facilities provided. The relationship between particular input mechanism and actions can easily be configured using a simple and intuitive 2D drag and drop schema. This interface also allows for the connection to other applications such as the pedestrian simulation (Figure 3 left).
5. The ARTHUR system has integrated a major CAD system (MicroStation) enabling architects and engineers to directly create and manipulate a virtual (CAD) model during design and review sessions. The virtual model is displayed on top of the Augmented Round Table using the head mounted displays. By using a 3D pointer or finger gestures, the users are able to draw directly in the (augmented) real world, without having to use a separate CAD workstation. Virtual menus floating above the Augmented Round Table allow CAD tools to be selected, e.g. drawing b-spline curves, spheres and tori, as well as extruding surfaces and changing colors. After selecting a tool users are able to draw the appropriate objects in 3D space. Additionally, the users are able to move and delete objects The virtual menus are bound to placeholder objects (Figure 3 right) and therefore can be moved around on the table to get them into the view or move them out of the view to enlarge the working space. The system architecture will allow all tools and functionality of the CAD software to be integrated into the ARTHUR system, e.g. solid modelling, constraint solving, etc. As such, 'full fidelity' CAD models are created and interactively displayed by the system; there are no translation or conversion issues and the CAD models can be used directly in downstream design processes (Broll et al, 2004).

5. Evaluation and Discussion

We have reported elsewhere on preliminary usability evaluation performed by the application partners as part of the early prototyping development, and the formal user tests with associated observations and questionnaires (Penn et al, 2004).

In this paper we discuss issues related to the inte-

Figure 3
Linking the agent software in GRAIL (left). Interaction with CAD menus in ARTHUR (right).

gration with CAD (Microstation) and report on early findings related to the evaluation of the system as part of the ARTHUR public demonstration at the Fair for Information Technology and Telecommunications (CeBIT 2004) in Hanover. We then review findings from the system in use with simulated pedestrian movement on the design table, including qualitative feedback.

Seamless Integration with CAD System

The design process uses a wide range of media and tools, with continual cycles of creation and modification followed by review. Although CAD has become a cornerstone of the design process, it is infrequently used for either the initial stages of design or review. Traditionally reviews are carried out using physical models or paper drawings. Although these have advantages over CAD in terms of accessibility to end-users, they are effectively static snapshots of the design, which can take considerable time to prepare. Any design decisions taken during the review meeting have to be implemented off-line before they can be reviewed again, which greatly increases the design cycle time. Although there has been considerable research into the use of VR environments to review CAD models, they still suffer from the same problem as 'physical' media, namely the reviewers are still reviewing an effectively static snapshot of the design, since there are no serious tools with which to manipulate the design. It became clear that the correct strategy was to integrate intuitive interfaces with the creation tools, rather than bring a static design model into an intuitive environment. As ARTHUR is a multi-user system, all changes applied to the virtual model are directly and instantly visible to all participants in the design session.

Therefore, design decisions can be evaluated immediately without the need to wait to discuss the effect of changes. In addition to the design review task, the seamless CAD integration is also very useful for initial concept design sessions. The finger gestures and the finger pointer are especially powerful tools for sketching or drawing b-spline curves and surfaces. The head-tracked stereoscopic displays enable a sense of immersion and ease of navigation that compares well to a physical model, and as such the system permits a more intuitive and expressive creativity compared to the 2D windows and mouse of a traditional CAD interface.

Results from user tests (Church scenario)

User tests were conducted on a regular basis throughout the ARTHUR project. Beginning with simple scenarios involving only limited interaction, test scenes were gradually enhanced to become more sophisticated and more reflective of architectural design and collaboration.

The most recent scenario was presented to a wide audience at CeBIT 2004 – an ideal testing grounds with a broad scope of unbiased testees. The scenario includes not only design evaluation tasks but also real form creation of simple geometries. It confronts the user with an urban context model with a free site in the middle. A 3D Pointer, PHOs and Gesture input are used to create and manipulate boxes, spheres, cylinders, and cones. The Pointer acts as a selection and manipulation device for objects and a selection device for 3D menus. The PHOs are connected to the two 3D menus in the scene as well as the example building. They are used to move and rotate these objects on the table plane. For technical reasons, Gesture input was seldom tested. Users mainly interacted with the 3D pointer and the PHOs. The task is to re-create an example 3D church model already placed within the scene. PHOs were easily used by all testees. Robust tracking and the "hands-on" quality ensured immediate use for moving and rotating 3D menus. Using the Pointer, however, revealed substantial differences between users. Although most users were quick to embrace the Pointer interaction, prior experience with MR-systems (mixed reality) as well as in part the "generation gap" seemed to be of substantial importance. People with prior experience were quick to comprehend the scene and interact with it easily. The same was true of several youths who gave the system a try. Acquainted with today's computer and video games, they seemed to have no problems moving on to the "next level" of Human Computer Interaction (HCI).

These users compensated easily for one of the major drawbacks in the current system setup that became obvious at CeBIT. Since a major part of object tracking is achieved using Head Mounted Cameras (HMCs), users had to be cautious to keep the 3D pointer in view of the HMCs at all times when interacting with the scene. The problem is one of perception. The tracking system sees the pointer as an object with one element: the colored markers attached to the front end. The user, however, sees two components. For one, there is the physical device itself (the user does not distinguish between the actual handle and the markers – it is one device). Secondly, there is the virtual selection beam emitted from the front end of the pointer. The user's point of orientation, however, is not the physical device but the virtual beam. A parallel seems to be the handling of a sword. A swordsman does not have to see the shaft of his sword – he keeps the blade in view instead.

Although testing time was limited for each individual, multi-user interaction was permanently sparked by the situation of sitting opposite one another and obviously manipulating the same scene. Users would exchange the virtual menus by pushing the PHOs towards the other user. Also, they would at times try to manipulate an object created by another user. It should be noted, however, that the latter seldom took place when the person who originally created the object was still present. Users seemed to view objects created by a particular user as, in a sense, belonging to that user.

All in all, the CeBIT test runs were highly successful. They provided not only valuable feedback on shortcomings, more importantly they verified the approach and the direction taken in developing ARTHUR. Most users quickly got into using the system and were then happy and willing to play with it and - on several occasions – test its limits (many users managed to scale the example church to several times its original size and seemed to enjoy the resulting dwarfing of the cityscape) (Figure 4).

Results from user tests (agents simulation scenario)

The second form of evaluation is related to the integration of simulated pedestrian movement on the design table.

Design sessions

Three design sessions were developed as an attempt to assess the impact of the real time interaction with the agents on a designer's approach to a design problem. Moreover the effect of simulation on the way designers collaborate is investigated.

In each session two users were asked to collaborate and construct a simple design solution using four walls as follows (Figure 5):

- The first session was conducted in a physical environment containing four fixed physical objects. Users were given four walls with which to construct the design solution.
- The second session was run within the ARTHUR AR environment, augmented with ten spatial agents that responded dynamically to

Figure 4
Multi user interactions and play with the church scale - CeBit 2004.

the changes in locations of objects on the table. After a short period of training with the system a group of two designers was asked to collaborate in designing the space with the help of the agents' simulation. Like the first session, the AR environment had four fixed digital objects; in addition, four virtual walls could be used to construct a design solution. These virtual walls were attached to the PHOs and so could be relocated by moving the PHOs. There were also two additional fixed digital blocks UG on the table. Agents move towards open space choosing a destination at random from the available space and walking towards it: their final destination was the UG.

- Finally the third session, which was again conducted in the physical environment. Users were asked in this session to go back to the physical environment, and try to reflect their AR experience, think of a design solution and then compare between the first and the third session.

Subjects and Analysis

Each experiment consisted of the three design sessions, described above. Four groups of designers were invited to go through the experiment; each group consisted of two collaborators and none of the users had any previous knowledge of the system. A brief description of the system was provided before starting the experiment. The form of collaboration was observed and notes were made of the difficulties the users experienced. The interaction, along with follow-up discussions, was videotaped for subsequent analysis with the consent of the subjects. This provided the researchers with a rich record of the complex setting, covering the interactions and difficulties experienced. More detailed feedback was documented in a form of a questionnaire. The observations reported here are mainly qualitative and derived from the video analysis of participants' interactions, discussions and questionnaires.

Observations and Discussion

Users' observations in the first design session indicated that designers were thinking of the design problem as a composition, trying to organize the walls in relation to the surrounding space, with less emphasis on other aspects such as movement. When users were faced with simulated pedestrian movement, in the second design session, their design approach changed. Movement in space became very essential and had a direct impact on the way designers perceived and understood the design problem. Users began to observe agents' behaviour and their reaction towards movement of the walls within the space. In this respect two key factors seemed to be very crucial: scale and time. As a result, and after watching agents move on the table for a period of time, users became immersed and therefore part of the interaction space: "Have you seen that guy (agent); as he saw the wall he turned 90 degrees in the other direction" (Fatah gen. Schieck et al, 2004). Users began to alter agents' movement pattern by moving walls to different locations and this influenced the emerging design. These interactions involved both designers and simulation agents and as a result this increased the level of collaboration.

Figure 5
Interactions in AR (left). Discussing how agents would have moved in the space (right).

In the third design session, users were asked to go back to the physical setting and rethink the design. We realised that their approach to the design problems had changed after the second session and the interaction with the agents. At the beginning of this session, all groups asked for two additional physical objects to add to the model. These were equivalent to the UG in the AR environment, which represented the entry and exit points of the agents. It seems that the presence of the UG helped designers to imagine the agents' behaviour and this encouraged discussions and collaboration. Unlike in the first session, the design approach in the third session was less focused on composition but was rather a combination of different factors strongly influenced by the perception of movement patterns (Figure 5 right). Results from observation of the design sessions indicated that, whilst the movement of an individual agent was not necessarily an aid to understanding the spatial configuration, the overall movement of a large number of agents was quite significant, which enabled users to make more informed decisions. Moreover it appeared that having an additional 2D analysis mapping the agents' traces was desirable as it helped the designers understand and compare different design proposals (Figure 6 right).

Subjects found the system to be both enjoyable and offer a potential for collaborative design and it appears that the interaction with the agents on the design table not only influences the way designers understand and design space, but also changes the way they approach design with physical models. Before experiencing the interaction with the agents the designers used a conventional way of designing. Conversely, the appearance of the agents on the design table encouraged the users to understand structures within space as a dynamic experience rather than a static one -through agents moving between spaces (Fatah gen. Schieck et al, 2004).

6. Conclusions and future work

This paper demonstrates that the conventional view of CAD in architectural design is changing. We present ARTHUR in an attempt to bring the computer – as an interactive and creative medium in its own right – onto the design table to support designers working collaboratively with seamless interaction techniques. The integration of existing CAD tools is described together with simulated agents' movement analysis.

Initial results from early forms of user evaluation suggest that ARTHUR may help throw light on the way that designers collaborate "We believe that creating architectural forms and working on a task collaboratively became a game that users enjoyed and consequently this increased their level of collaboration" (Penn et al, 2004). Tests at CeBIT went a long way towards underpinning this belief. Although many of the users were not trained designers, the general notion of "playing around" with the system was realized by most testees. Future tests will build on the experience gained from CeBIT test runs and will focus on trained architects and designers.

Building on the game metaphor, we have constructed design experiments in an attempt to explore the potential of real time interaction with simulated pedestrian movement on the design table. Observations of designers going through a cycle of reflection and action with the agents suggest that the integration of the pedestrian movement simulation played a vital role in exploring possible design solutions and

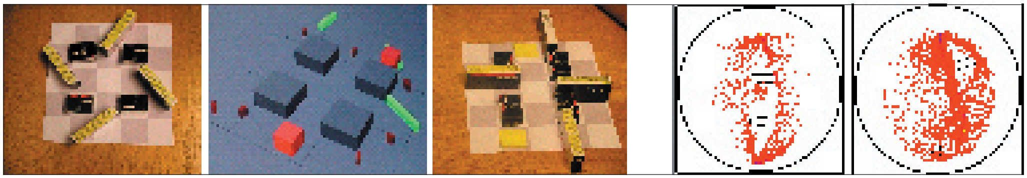

Figure 6
Experiment with 3 different design sessions (left). 2D representation of agents' traces (right).

encouraged different ways of thinking of a design problem. We believe that understanding of the design problem largely emerged through designers' observation of the agents' behavior and their interaction within the environment, characterizing an important dimension of the illustrated approach. This is supported by Negroponte "While a significant part of learning certainly comes from teaching… major measure comes from exploration, from reinventing the wheel and finding out for oneself . . . by playing with information, especially abstract subjects, the material assumes more meaning" (Negroponte, 1995). Augmenting the scene with simulations of pedestrian movement supports this, and moreover it seems that an additional visualization of the agents' traces in the 3D environment would help give the designers a more informed impression about the space.

In this paper we have also reported on an early stage in the CAD integration development process. However, it is clear that the integration of CAD into ARTHUR raises complex issues related to designers' input and the interaction techniques within Microstation. To cover these issues therefore, various experiments should be conducted, especially within the framework of providing natural interaction in a 3D collaboration environment using gestural input.

7. Acknowledgements

Extra contributions from O. Romell and I. Lindt. The ARTHUR project is partially funded by the European Commission IST program (IST-2000-28559).

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