

IS IT POSSIBLE TO DESIGN IN FULL SCALE?

A CAD Tool in a Synthetic Environment

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Abstract. This project developed a Virtual Architectural Design Tool (VADeT) executed in the C2 Virtual Reality (VR) space. C2 is a synthetic CAVE environment providing a full-scale setting for image projection and perception. Applying this tool for design offers four advantages over other CAD systems. First, it enables navigation performing in full scale to create the sense of immersion and reflection of the seeing-as. Second, it allows the creation, modification, and editing of three-dimensional objects in a virtual space. Third, designs can be modified and viewed simultaneously inside or outside of the generated model to obtain the best design products. Fourth, the entire design process can be recorded and played back. Collectively, this tool serves the purposes of: (1) a three-dimensional sketching tool for manipulating 3-D objects, (2) a design study tool for transparently displaying the design processes, and (3) a design teaching tool to demonstrate the processes by which designers do design. Thus, design in a full-scale representation not only is possible but also is a new and unconventional mode that will heavily influence design thinking.

1. Introduction

How feasible is it to do a design in full scale? Traditionally, architectural design begins with an idea in mind; then, either a two-dimensional concept is sketched on paper, or a three-dimensional study model is constructed to visually perceive the form and to evaluate the design product. Rarely will a designer do design in full scale. The convention of sketching in paper and constructing miniature models is very much culture-bound. Even though the conventional methods provide a means for cultivating ideas, they set up certain limits on stimulation and inspiration. Because designers cannot project themselves into the space in the same way as they are physically existing, the experience of seeing-as and reflection in-action (Schon, 1983) is limited, and the scope of design thinking is narrowed.

If a medium provides designers with an opportunity to see design interactively, a sense of projection into the design will be generated. Such a projection has the potential of yielding different perceptions of the design and diversifying the design process. In the design profession, diversity will broaden personal vision, enrich mental images, and stimulate multidirectional thinking.

All these are likely to improve design quality. Furthermore, diversified media applied in design will broaden thinking, change the design process, and enhance creativity. Any design medium that cultivates diversity can be seen as an appropriate future design tool.

Virtual Reality (VR), a very advanced human-computer interaction tool (Durlach & Mavor, 1995; Mine, 1995), provides diversified media for visually, aurally, and interactively experiencing activities and behaviors conducted in the cyberspace. Applying VR to design, its immersive and interactive nature enables designers to perceive, grasp, and manipulate three-dimensional (3-D) building elements in the VR space. Implementing design in VR, designers can immediately understand the spatial qualities, visualize the color and texture of materials, comprehend the major components of the HVAC system, experience the proportions of the spatial layout, and appreciate the aesthetic expression of the structural elements. Design taught in this fashion will be very effective, and professional design projects done in VR will have great potential for communication and presentation (Biocca, 1992).

Most of the current VR environments (Brooks, et al., 1992, Ellis, 1991a; 1991b; Pimentel and Teixeira, 1993), however, require the use of other computer modeling packages such as Softimage or MultiGen to complete a building model first before it is imported and displayed. This method limits the flexibility and plasticity of VR's application to the schematic design stage, and allows VR technology to be used only as a production tool instead of a design tool. A number of other researchers are working on producing a virtual walkthrough space to build 3-D shapes (Butterworth, Davinson, Hench & Olano, 1992; Halliday & Green, 1994). Their efforts are focused on the algorithms and techniques required for shape construction, placement, and interaction. To develop an appropriate design tool in VR, efforts must concentrate on exploring means to simulate an environment for users to create digital models and to evaluate the design processes and products. Following this line of thought, this project has developed such a VR design tool to: (1) enable designers to create 3-D digital models and to experience 3-D design at the early concept-formation stage, (2) facilitate the evaluation of design decisions made much earlier than with conventional design methods, and (3) create a more transparent tool for virtual perception of the creative processes.

2. A design tool in VR

In a conventional design method, if a full-scale model is built, designers can discover from the model whether a doorway is too large, an access space is too limited, or a beam is not in the right position. The entire section of a building then needs to be redesigned and the mock-up rebuilt. Of course, building such a

physical model is time consuming and expensive, which in most cases makes it unfeasible.

VR, with its immersive and interactive capabilities, allows full-scale virtual models to be constructed at a greatly reduced cost. However, most current VR environments for architectural design either are primitive or require external modeling packages to get a good visual exploration. Whenever mistakes are found in the model while exploring it in the virtual environment, corrections cannot be made immediately. Modifications have to be done offline once the exploration is completed. Moreover, it is not always feasible to compare the new design with the old version just by reloading a database. The lack of immediate interaction and feedback may cause visual perception errors while modifying the design in a more traditional modeling package. Further, the user may not recall the exact design flaw observed in the virtual setting. On the other hand, a design cannot be done in VR without having tools available. If there are building materials and modeling operators at hand in the VR space, designers can simply select and build rather than construct the model elsewhere. Therefore, an online computer model and methods of saving design data are needed. This is the notion of building up a CAD system in the VR environment to assist design (Sutherland 1965, Foley, et al. 1990, Stuart, 1996).

Thus, the Virtual Architectural Design Tool (VADeT) is developed as a proof-of-concept test bed to advance the techniques of establishing a design tool in a full-scale space. The C2, based on the CAVE system (Cruz-Neira, Sandin & DeFanti, 1993), is not only an immersive and interactive setting but also a full-scale space for projection and perception providing the place to implement the concept. Inside the C2, this VADeT system has a number of metaphorical icons symbolizing tools for selection. Tools are available for defining materials and colors, and hierarchical 3-D solid modeling operations can build up, take away, and edit an electronic building online.

3. VADeT Hardware

VADeT uses the C2 input devices to enable the direct manipulation of objects and an immediate stereoscopic display of the effect of a user's actions. The four surround-screen display system of the C2 uses LCD shutter glasses for the stereoscopic display and electromagnetic sensors for head and hand tracking. The C2 is controlled by two Silicon Graphics Inc. 12-processor Power Onyx mainframes, each of which features two Infinite Reality graphics engines. A 3-D audio system provides localized sound. The VADeT system can also be used in an n-Vision head-mounted display equipped with the same tracking and input devices as the C2.

4. VADeT tool

The system starts by presenting the user with an empty space delimited by a floor, a 3-D grid (Figure 1), and a set of icons representing the initial design tools (Figure 1). There are five major groups of design tools provided from the tool palette: entity¹ creation, editing, color and texture, storage and retrieval, and recording of the design processes. The hierarchy of menu selection is of standard tree structure. The five major tool groups are installed on the root level. Each group's associated submenu will be activated once it is selected. In the following, details about the five major groups are explained briefly.

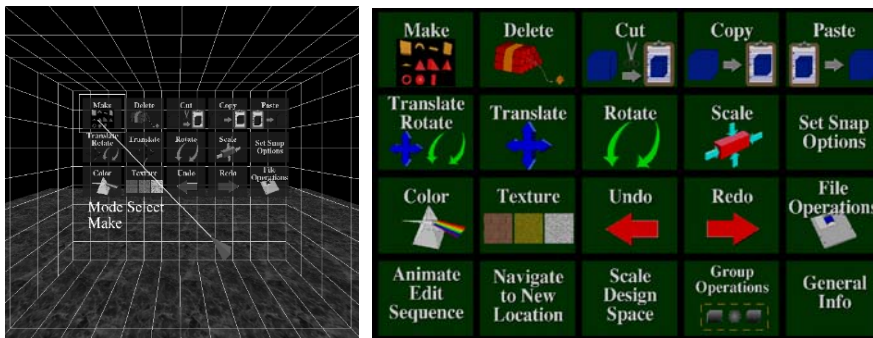


Figure 1. VADeT initial environment and the main tool palette.

4.1. ENTITY CREATION AND PLACEMENT

The entity creation group is marked as "make" option in the tool palette. It allows users to interactively select a basic entity and place it in the 3-D space. Users can select and place as many entities as they require (within system memory constraints). Numerous entities can be grouped into one entity and the modifications made will be propagated to the entire group. The main coordinate axes for the space creation are located in the scene of the C2. The coordinate axis arrows seem to be attached to the wand position. The current VADeT system provides 11 predefined, primitive solid entities of box, cylinder, torus, wedge, sphere, pyramid, and cone (see Figure 2). Several entities represent building structural elements, for instance, box of wall and beam, torus of arch, cylinder of column, etc. In the future, users will be able to customize their own building blocks and elements.

¹In this article, the term "entity" represents shapes and objects.

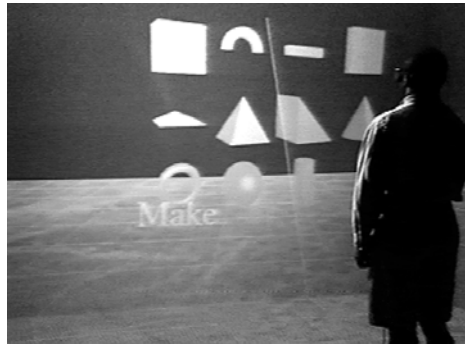


Figure 2. Shape selection palette.

4.2. ENTITY EDITING

After entities are created in the virtual space, designers can modify their location and size by applying the translate, rotate, and scale operations. Because accurate placement of objects in 3-D space is not an easy task, several modes of translation, rotation, and scale have been further developed. The first mode of free motion does not restrict the entity manipulation. This is useful for translating in a large distance, and designers can quickly place the entity at an approximate location. In the second mode, designers can put constraints on how the transformations apply to the entity. For instance, translations and rotations can be restricted to only one axis under a certain degree of values. The third mode is the "snap-to-grid-and-angle" constraint, which sets the granularity of the grid and angles. Entities can be copied, cut and pasted, and deleted in much the same way as the utilities applied in most of the CAD systems. A clipboard has been implemented to save the entities and their attributes during the copy, cut, and paste operations.

4.3. COLOR AND TEXTURES

Colors and textures are unique elements in design. Decisions about particular colors and textures are determined by the designer's personal preference, design knowledge, and aesthetic appreciation. Currently, the system treats these aspects as informational issues. Thus, several tools have been developed to serve as information resources for decision making. One tool is the color palette² (Figure 3). This palette uses an HSV and RGB color mode to obtain the right shade for objects. The second tool is a texture palette (Figure 4) which has fundamental

² The Color selection window is a part of Daniel Heath's Virtual User Interface project developed at ICEMT.

building materials for major structural components. Designers can assign and reassign any color or texture to the generated objects.

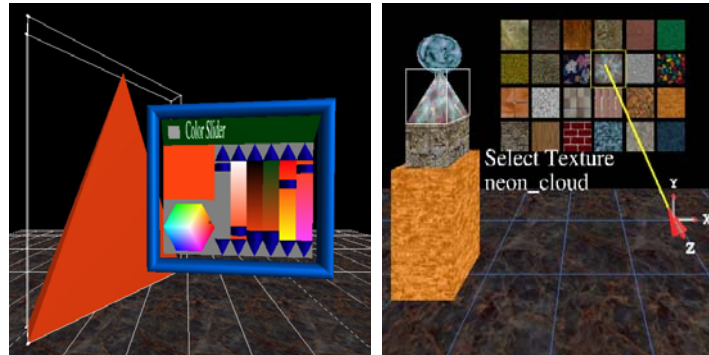


Figure 3. Color palette and texture palette.

4.4. MODEL STORAGE AND RETRIEVAL

One of the key features of VADeT is the ability to save the design at any time during the interactive session. The saved design can be retrieved for future design sessions. The goal is to allow the entire design process to be done from within the virtual environment. Currently, VADeT stores the model and all attributes in a custom file format. To achieve compatibility in importing and exporting models from VADeT to other tools, other popular model formats, i.e., VRML, dxf, and flt, will be considered in the future.

4.5. RECORDING THE DESIGN PROCESS

The series of design actions can be recorded in the order they are performed in the system. This is to achieve the goal of allowing "undo" and "redo" operations. Because design is a creative process, it is very likely that designers change their minds as the design is evolving. It also serves the goal of making VADeT not only a design tool, but also a teaching tool. For instance, saving the design actions of a master architect provides students with valuable data to learn what design methodology is used, how the different entities are combined, why a design action is creative, and what steps lead toward achieving such a creative level.

4.6. HEADS-UP DISPLAY

During the design process, the information about the actual dimensions of entities and parameters of the operators might be needed as visual aids for

perceptive purposes. Therefore, a heads-up display feature is implemented that displays the status, parameters, and attributes of the user's actions. Figure 4 shows an example of heads-up display during a translation operation.



Figure 4. Heads-up display showing the operation of translation.

5. VADeT implementation and its system architecture

VADeT has been designed using an object-oriented approach, focusing on supporting interactive performance, incremental development, extensibility and display interface independency. A set of C++ classes comprises the main core of the system. Three main classes are defined to correspond to the main objects that constitute the system: the environment class, the palette class, and the shape class.

The environment class is the top-level class, which contains all the member functions required to control the execution of a VADeT session. It includes member functions to build the model, to process a user's actions, and to coordinate the communication between the palette and the shape classes. The system design environments in C2 as well as in the head-mounted display are fully immersive. The C2 software library abstracts the implementation and configuration of the VR devices, providing flexibility in adding new immersive devices to be used in the VADeT system.

The palette class is the parent of two subclasses: the input palette and the picking palette. The input palette class is the parent for objects that allow input, such as the color palette. The picking palette class is used for objects where only optional selections are allowed, such as the main palette.

The shape classes maintain all the different entities supported by the system. These classes maintain shape attributes such as location, orientation, color, and texture, as well as the shape modification history. The shapelist classes maintain

a "clipboard" which is used to perform cut, copy, and paste operations. The control and synchronization of the C2 and the head-mounted display are handled by the C2 software library (Cruz-Neira, et al., 1993); its discussion is beyond the scope of this paper.

6. The impact of design in full scale

VADeT provides designers with a chance to explore full-scale virtual models at any design stage. Right after the system is started, users can select a desired icon from the menu, modify the object to fit its real dimensions, and then place it on the right position. The system has the snap-to-grid function for accurately revising the dimensions. Because the objects in a full-scale model are large, it is not easy for designers to quickly move a large entity within the design space. The virtual design space is larger than the physical size of the C2 system. Thus, a navigation tool is provided to let designers move easily to new locations within the virtual space.

Navigating through spaces in VADeT is quick, and the change of perspective is very mobile. Objects can be generated, copied, deleted, moved, scaled, or regenerated in real size without difficulty. The whole process can be saved, reentered, and remodified. These unique characteristics provide a greater degree of flexibility for designing than traditional sketch-and-model methods. In this regard, this system can be seen as a three-dimensional sketching tool.

A full-scale model, however, also limits immediate perception of the entire site and its adjacent context and presents problems for immediately comprehending relationships among objects macro-wide. This is similar to a designer who has difficulties perceiving the scene of a city block while he or she is at the street level or inside the building. Such limitations may constrain the immediate response of reflection projected between the designer and the design status, and may block the spring of immediate intuition. Thus, in the schematic design stage for concept generation, the best solution is to control the scale mechanisms. In other words, use small scale to build large objects and to view exteriors, then explore the inside in full scale after the overall form is generated.

In sum, a full-scale model provides an excellent environment for understanding the interior spatial layout and structural components; thus, it is a very good tool for perceiving and simulating reality. Figure 5 is a kitchen design example generated by the VADeT tool.

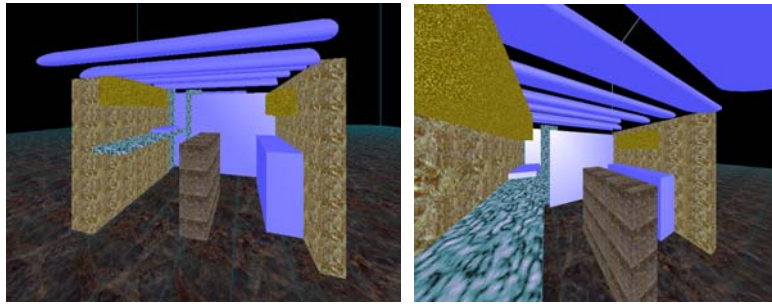


Figure 5. A kitchen design example.

7. Future direction

Virtual Reality (VR) is a new technology allowing users to step through the computer screen into a three-dimensional artificial world. To further design in the artificial world, users should be able to manipulate objects naturally in the virtual space with their eyes, feet, and hands. To this end, new methods of modeling architectural objects directly in VR need to be further explored -- especially the freedom of deformation and the set operators required to make organic forms. This will make the object generation processes more sculpturally oriented.

Other than the customization of building blocks, the system should also support standard data formats to import existing models into VADeT and export VADeT models to other modeling packages. More sophisticated lighting controls have to be included in order to provide a better visual effect for a final design.

The long-term goals of this system are to combine information technology and Virtual Reality technology to establish an interactive architectural design and learning environment. The recording and redisplay capabilities of VADeT characterize its use as a tool for observing designers' thinking process to understand how a full-scale representation would affect design thinking. Given the opportunity to visualize the design process in VR, audiences will be able to understand the myth of how master architects perform their creative works. VADeT can be used as a research tool for design studies.

Finally, VADeT should eventually support collaborative design processes and verbal communication through the Internet. With such an environment provided in different locations and linked together, designers could see and share information. If the system could collect data and send them to different sites in different countries, designers would learn various design principles, methods, and processes inherited in various design cultures. Potential clients from different parties could visualize results and provide feedback instantly. This would transcend geographical boundaries to allow architectural design to be

taught, learned, seen, and touched from different locations to improve design thinking.

Acknowledgements

The authors gratefully acknowledge the support of the Special Research Initiation Grant (SPRIG), 1997, Iowa State University, and Study in a Second Discipline Grant, Spring 1997, ISU.

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