

Virtual Architectural Design Tool (VADeT)

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Abstract

The Virtual Architectural Design Tool (VADeT) is a prototype of an immersive environment for interactive architectural design. VADeT provides computer-aided design (CAD) capabilities inside the C2 immersive virtual environment to establish a new, diversified tool for architectural design. Applying this tool to the design process will enhance the conventional method of sketching a design concept on paper and it will stimulate thinking by enabling direct exploration of the design as it is being developed. This new approach to architectural design allows architects to gradually build models in a virtual environment at various scales.

VADeT presents designers with operation selection menus to create and modify architectural primitives. Interaction is performed with a three-button six degree-of-freedom wand. The current editing features include shape placement, orientation, scale, color, texture, copy, cut, paste, and group operations. VADeT also allows for user navigation and model scaling as well as animation, storage, and retrieval of the design process.

Keywords

Virtual Reality, Architecture, Design, ICEMT, Immersive Environment, C2, Computer Aided Design.

1. Background

In the last century, the design process has been revolutionized by the increasing presence of the computer technology [3]. The term design process can be applied to a wide range of activities including VLSI computer chip design, automotive design, or the creation of multimedia content. This introduction will provide a brief overview of a design process in order to introduce the concept of the VADeT system.

Today's design processes often involve a user working with a keyboard, mouse and/or other input device to create a computer model. The user views a design from a perspective or orthogonal view on a two-dimensional monitor or large screen. Users perform a variety of manipulations to create and view geometry. They may type coordinate system values and abbreviated command names. They may select operations from a plethora of on screen graphical buttons and menus. Once a model is thought to be complete, a physical mock-up is made. If errors are discovered, the computer model is corrected and another mock-up is created. This costly process is repeated several times.

The introduction of Virtual Reality (VR), an advanced human-computer interaction tool, [8][14] has enhanced the design process. VR brings the capability to immersively view a three-dimensional design at different levels of detail, from several perspectives, and at various scale sizes, before creating a final product. The use of VR can reduce design time and cost through intuitive design exploration [2].

One limitation of the VR augmented design process is that the development and inspection of a design occur in two separate applications. This separation can impose several restrictions on the design process. Time and tedious effort are often required to move between VR and external CAD systems. It is

often the case that design modifications cannot be performed upon discovery in the VR setting. These problems can be minimized by carefully integrating the design tool and the VR inspection into a single immersive virtual environment.

There have been a number of efforts to create a virtual workspace for designing three dimensional shapes. The Conceptual Design Space allows users to develop conceptual building designs. The system allows users to then inspect, inhabit and perform modifications on designs through the use of a head mounted display system [1]. The ErgoSketch system presents a new interaction paradigm for the Active Desk, a variant of the responsive workbench. An ErgoSketch user performs 3D modeling tasks by drawing 2D gesture lines on the Active Desk. ErgoSketch also features two-handed interactions, speech input, and seamless transitions between 2D and 3D interaction tools [9][10]. COVIRDS (Conceptual VIRTUAL Design System) also provides a 3D environment for shape design. COVIRDS uses speech recognition and a three dimensional input device to provide geometric, parametric, and free form shape design operations in a Virtual Environment. The COVIRDS application is presented on a large inclined projection screen [7]. CALVIN is a prototype CAVE application for collaborative visualization and architectural design. CALVIN is used to study the issues relating to multi-user interaction [13].

The design process specifically targeted by this application is that of architectural design. This paper discusses the Virtual Architectural Design Tool (VADeT) (Fig. 1). The aim of VADeT is to incorporate CAD design capabilities into a virtual environment. The end result is a tool in which architects create, modify, and evaluate designs from a single application executing on a VR system. This paper discusses several aspects of VADeT.



Figure 1. Users in the VADeT System.

2. Concept

VADeT is an application that allows 3D modeling to take place in a virtual environment. VADeT is designed to be an interactive and efficient architectural design system. To qualify as such, it must provide operations to model, display, modify, explore, store, and retrieve a design. Modeling operations include creating three dimensional design primitives, placing these objects into a design, and setting object attributes (i.e. color, texture). Display operations present the design to reflect the appearance of the objects if physically created. Modifier operations allow users to change the objects in the design. Exploration operations allow the user study the design from various perspectives. The user should be able to view a design from any location and/or orientation. The user must be free to focus on only the necessary design details. Storage and retrieval operations allow users to perform the design over multiple work sessions and distribute designs to other individuals.

VR provides a sophisticated human-computer interface with immersive and interactive characteristics. Through a VR system, a user experiences the sense of presence in another world. VADeT immerses a user inside of a virtual environment with their design and with flexible methods for performing CAD operations [2].

3. Hardware

The VADeT system utilizes the C2, a surround-screen display system [5] at the Iowa Center for Emerging Manufacturing Technology, to convey the sense of an immersive environment. The C2 uses four projection surfaces arranged in a cube-like fashion (front, floor, left, and right) to display stereo computer graphics. Users wear LCD shutter glasses to facilitate the stereo viewing. The C2 uses an electromagnetic tracking system to gather user and input device position and orientation information. The C2 system also features a four-channel positional sound system that can be used to give audible feedback to users. VADeT can also execute on other VR systems (head-mounted display, power-wall) with similar tracking and input devices as the C2.

4. User Environment

VADeT allows for flexible and convenient user interaction. This section discusses user information cues and methods for modifying, viewing, storing, and retrieving of a design. The discussion of these interaction aspects specifically addresses VADeT operation in the C2.

4.1 Information Cues

The VADeT environment presents several visual and audio cues to aid in the design process. The visual cues include design space grid lines, mode and item selection menus, a 'heads-up' information display, a wand position indicator, coordinate system axis, and a color selection window. Audio cues include sounds played upon key user operations.

The design space grid lines are used to judge the placement of objects in a design (Fig. 2). This grid can be used to place objects at specific coordinate locations. Users may also use these lines to judge the relative placement of two objects in the design space. Additional lines extending from the center of an object to a position on the grid are used to 'trace' the position of the object in the design space.

The mode and item selection menus are the primary tools for user selection (Fig. 2). Users interact with these menus to select the type or mode of operation to be performed. Menu operations are represented with visual icons and text. These menus provide access to all available edit modes and other sub-menus within the edit mode hierarchy. Interaction with these menus is discussed in section 4.2

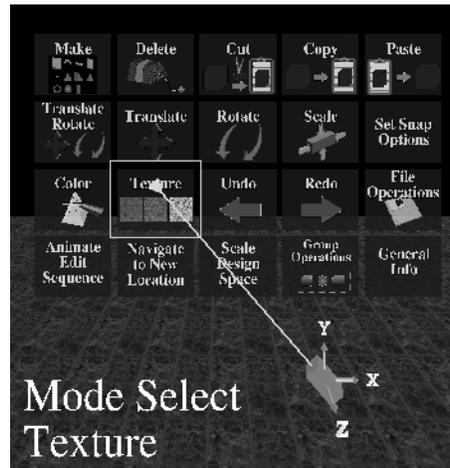


Figure 2. Mode Select Menu, Heads-up Display and Wand Position Indicator

The shape palette displays all available design primitives (Fig. 3). Users interact with this menu similarly to the edit mode menu. The shapes currently available in the VADeT system include cube, wall, arch, beam, roof, pyramid, wedge, cone, torus, sphere, and column.

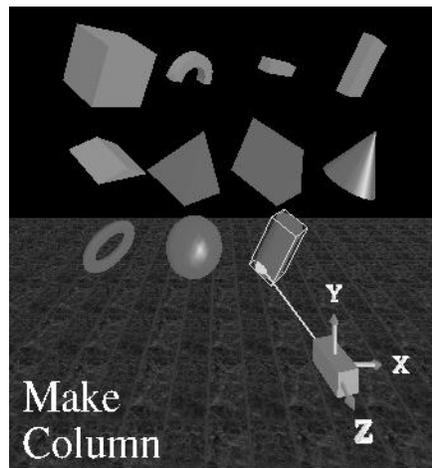


Figure 3. Shape Palette

A wand position indicator shows the tracked position of the wand input-device in the virtual space (Fig. 2). This indicator is important for users attempting to select detailed features within a design. The wand position indicator is coupled with a coordinate axis display. This axis matches the orientation of the world coordinate system to illustrate the direction of the X, Y, and Z-axes.

The heads up display (Fig. 2, Fig. 4) presents alphanumeric data to the user. This display indicates the current edit mode, the value of a modified object attribute (position, orientation, and color), or other status related to a current operation.

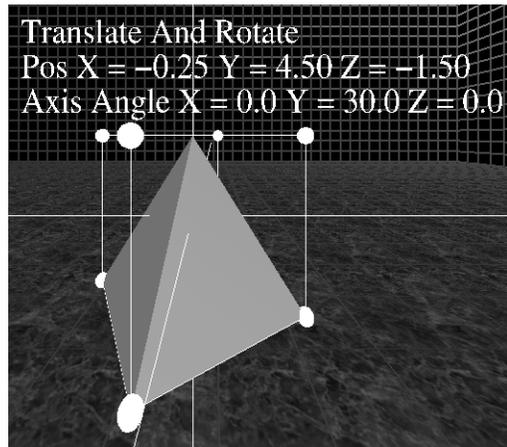


Figure 4. Heads-up display II

Object colors are selected through the color selection window (Fig. 5). This window is present while the color-editing mode is active. This window is used to select and apply a color to an object via RGB-HSV (red, green, blue, hue, saturation, and value) sliders or a color wheel. This window is part of the Virtual User Interface developed by Daniel Heath at ICEMT (Fig. 5.) [12].

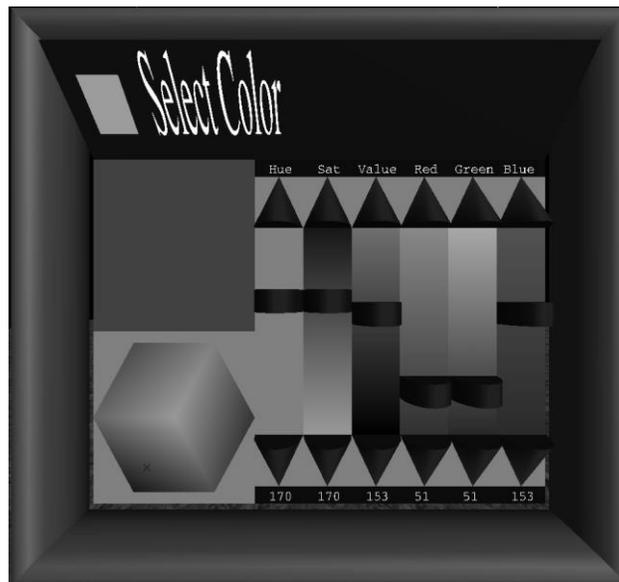


Figure 5. VUI Color Window

VADeT users also receive sound feedback when design events occur. Sounds are played when users perform menu operations and during most shape modification operations.

4.2 Interaction

VADeT users interact with the system via a three-button wand with six degree-of-freedom tracking. Pressing the buttons and/or manipulating the wand position and orientation performs user actions. The

buttons on the wand represent a set of VADeT actions that are grouped by similarity in purpose (Table 1). The grouping simplifies the introduction of new users to the tool. New users need only be told the general rules about the three buttons to begin design work.

<u>Button Number</u>	<u>Button Action Set</u>
Button 1	Perform Object Modification {translate, rotate, scale, color}
Button 2	Select Object {select_object_for_modification, deselect_object}
Button 3	Menu Operations {raise_menu, lower_menu, select_menu_item}

Table 1: Three-Button Wand action sets

Object modification and selection are discussed in section 4.3.

Menu operations give the user an exact input method. A user presses (and releases) the menu operations button to cause the main menu (Fig. 2.) to appear. The user may highlight an option on the menu by aiming the wand toward the desired option. Upon repressing the menu operations button, the highlighted operation is selected. If no operation is selected, the menu disappears.

4.3 Design Modification

Users design in VADeT by performing a combination of mode selections, shape selections, and object modifications. A user may select and/or modify a shape in any order. This section describes the process of mode selection, shape selection, and shape modification.

There are several operating modes in VADeT. The modes are grouped by similarity of purpose. These modes are selected through the main (Fig. 2.) and auxiliary mode menus. Table 2 lists the main set of design modes.

<u>Mode Group</u>	<u>Edit Mode</u>
Object Creation	Make, Delete
Clipboard Operations	Cut, Copy, Paste
Object Editing	Place Object, Translate, Rotate, Group
Object Appearances	Color, Texture
Design Process	Undo, Redo, Animate Edit Sequence
Design Viewing	Scale Overall Design, Navigate

Table 2. VADeT Edit Modes

Design components are selected for modification by wand proximity to the object or ray casting while pressing the Select Object button. While pressing the Select Object, VADeT draws a ray extending from the top of the wand outward into the design space (Fig. 4). Once the select button is released, the selected object is marked for modification by a color change and shape boundary marker (Fig. 4).

Once an edit mode has been selected, and a shape has been identified for modification, users edit the shape with the modify object button. This button will perform the selected modification on the selected object.

4.4 Group Operations

VADeT provides grouping operations to allow users to work with a collection of objects simultaneously. VADeT operations permit users to create groups, add objects to groups, and ungroup groups. VADeT users may add objects to groups singularly, or by placing a bounding box around the members of a group. All objects within the bounding box will be added to the group. (Fig. 6).

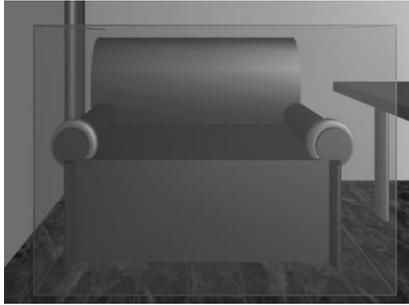


Figure 6. Group Selection Volume

Once groups have been identified, all objects in the group will have editing operations performed on them as a single object. Groups can be chained together in a hierarchical fashion.

4.5 User Perspective

VADeT user perspective is controlled through head (and body) movement, navigation through the design space, and scaling the design space.

Users are free to move within the 12' X 12' X 9' volume of the C2. A user may change the position and orientation of his/her head to view different sides of the design. Users may navigate to interact with geometry outside of the volume of the C2. When selected, navigation mode allows users to navigate and/or rotate in the direction indicated by the wand.

Users may also change the design scale throughout the design process. A user may select from a few typical design scales (2X, full-scale, 1/2, 1/8), or vary the scale incrementally. By doing so, users may add detailed geometry to portions of designs while in exaggerated scale, or view the entire scene in miniature.

4.6 Design Recording and Playback

VADeT logs design modifications as they are performed. These actions can be replayed to study an individual's design process. Users may also review a portion of a design process and then begin new modifications on the design from that point onward.

4.7 Model Storage and Retrieval

VADeT currently stores model information in an arbitrary file format. The file format stores the characteristics of design objects (position, orientation, textures, scale) as well as information about the sequence of edit operations. This information may be saved and loaded from within the immersive environment. (Fig. 7). VADeT also has the capability to load from '.geo' format file into an editable object.

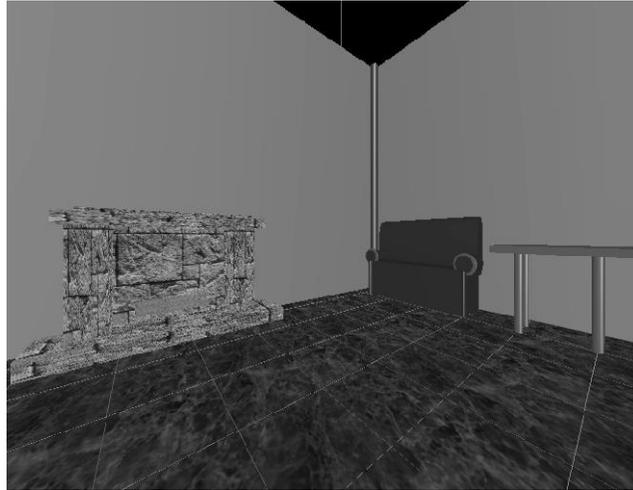


Figure 7. A Multi-session design

5. Implementation

The VADeT application is implemented in a layered C++ object-oriented fashion. This structure allows for incremental development and extensibility. It also allows for display interface independence [4]. The computer graphics are drawn through an OpenGL version of the C2 libraries.

VADeT features several classes including Environment, Shape List, Shape Classes, Menus {Floating Menu, Shape Menu}, File Input-Output, and Sound.

The VADeT environment class handles user actions and manipulates the Shape List class. The Environment class contains the draw and frame functions. It updates all current editing mode state variables. It also determines which information cues should be used and updates the cues as required.

The Shape List stores and manipulates design objects. The Shape List is an unordered list of all objects in the design space. This class provides list iterators, contains design modification history information, and handles clipboard operations.

VADeT objects use inheritance and virtual functions. The VADeT basic shape class features operations for setting shape attributes, drawing objects, and determining shape selection. All VADeT shapes inherit the properties of a basic shape. Some VADeT shapes define exclusive attributes not shared by all shapes. One example of such an attribute includes the inner and outer radius of a torus.

The Floating Menu Class manages the floating mode selection menus (Fig. 2). This class can create horizontal, vertical, or tiled menus. The Shape Menu class is a modified version of the floating menus, which displays VADeT shapes (Fig. 3). This menu is animated to show the users all views of the selectable objects.

The File Input-Output class stores and retrieves VADeT design information. This class will facilitate future file format changes. The Sound Class interfaces with the AudioWorks sound server. This class triggers the sounds that are played upon menu interaction or object modification.

6. Discussion

Several findings about the usability of the system have been obtained from user testing (Fig. 8). More details about the test procedure can be found in [4]. In this section we mention a few general results from the user testing.

Users were able to learn the basic operations of the VADeT system in a short amount of time. It took users between 10 and 20 minutes to feel comfortable enough to begin design work. Users reported that the methods for selecting objects and editing modes are very flexible and user friendly. Users also made requests for additional system features. One request was to add the capability to lock completed objects to prevent unintended changes. Another request was to add free form sculpting methods to create organic forms.

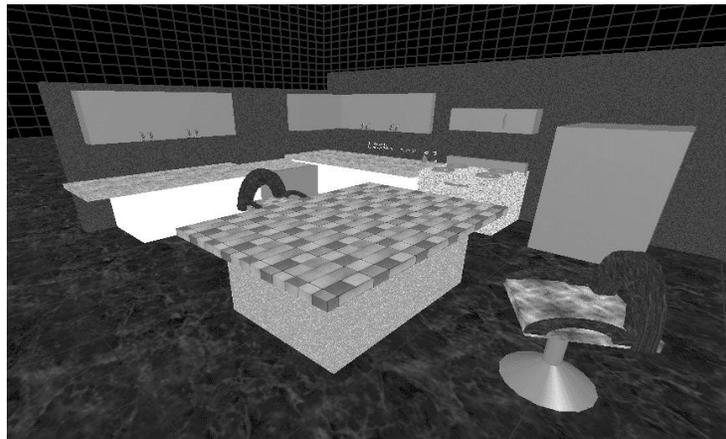


Figure 8. Kitchen Design User Test

User testing also revealed an unexpected method of performing virtual design. The author's typical design method has been to navigate so that the desired object location was within the volume of the C2. Then, using the body as a reference, create, scale and place the object. In an interesting variation, one user first created a component of a scene within the physical space. The user then sized and/or colored the object. Once satisfied with the object the user 'pushed' the component forward into the scene to final position beyond the physical C2 design space. This behavior seemed to mimic the method for miniature model design: first create an element, then place the element into the scene. An interesting study would be to compare and contrast virtual object construction methods with the physical small-scale design modeling practices.

7. Future Development

VADeT is a testbed for the integration of CAD methods into a virtual environment. An immense amount of effort would be required to make it comparable to professionally developed CAD systems. In the never-ending attempt to do so, there are several areas of possible future development.

VADeT could use formal CAD software methods to manage data associated with the design process. Examples of this data include object attributes, a grouping hierarchy, or an object history. An improved method might include implementing a distributed database for managing shape manipulations, as opposed to the current Shape List. This would allow for collaboration in multi-user design spaces.

At present all VADeT shapes are predefined architectural and modeling primitives. VADeT will need

major modifications to facilitate constructive solid geometry operations or polygonal representations of geometry. Users may wish to import, create, or modify custom geometry from non-.geo file formats. The interface needed to load these primitives is still in development. Creating and modifying custom geometry will require a polygonal or mathematical representation of geometry and an interface for interacting with such geometry. This type of interaction is presently being researched at ICEMT [11][15].

Further work can be done to improve shape interaction methods. Improvements might include constrained translate, rotate, and scale operations. Users may wish to place one object directly on top of another in a method which mimics the effect of gravity. The shapes should provide special interaction handles. Selection of these handles should determine the type of modification that is to be performed.

Improving shape interactions will also reduce the amount of time a user has to spend selecting menu icons. The addition of a speech recognition system for interpreting user commands will further reduce this time.

8. Observations and Conclusions

VADeT has demonstrated that integrating CAD capabilities into a virtual environment is an important step in the design process. VADeT presents an immersive, immediate, and intuitive visual representation a design. This application also allows users to refine a design and review its creative process. Even the most novice computer user can easily understand the combination of these capabilities during their first use of the application.

VADeT allows for a variety of traditional and non-traditional architectural design methods. Architects are presented with familiar operations for creating, modifying, and storing a design. VADeT also presents specialized operations for viewing and modifying a design from various perspectives. VADeT's capability to interact with a design in various scales has sparked interest into the feasibility of full-scale design in the architectural community [3,4].

Future VADeT development will further incorporate the result of many studies of user interaction in immersive environments. These studies will enhance the current VADeT information cues, interaction, and input devices to make the design process an even more intuitive experience. Other enhancements to the VADeT system will enable users to work with a variety of file formats. Inter-application compatibility will increase user receptiveness of this type of application in industrial settings and encourage further development of similar systems. The object-oriented implementation of the system permits individual components of the application to be refined independent of each other.

9. Acknowledgments

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