Establishing Virtual Design Environments in Architectural Practice

Charles E. Dagit III

Worldesign, Inc.
5348-1/2 Ballard Avenue
Seattle, WA 98107 USA

This paper attempts to specify the ideal computerized architectural design tool and outlines steps that are being taken to make this ideal a reality. Section 2 offers a user-centered assessment of the way technology is currently implemented in the design professions. Section 3 describes the state-of-the-art in high-end CAAD applications, including computer rendering, walk-through displays, and expert diagnostic systems. Section 4 details work in progress at Worldesign, Inc., a virtual worlds systems integration firm, which is developing Virtual Design Environment (VDE) systems.

Keywords: computer-aided architectural design (CAAD), computer-aided engineering (CAE), virtual worlds technology, visualization, computer generated environments, computer modeling, virtual reality, information systems, information design.

1 Introduction

The concept of "virtual reality," or more precisely *virtual worlds technologies*, has recently garnered a great deal of attention, especially from those in the architectural field. Architects are attracted to the "sexiness" of an exciting new medium, and the much touted potential for a radical paradigm shift. At the same time there has been a skeptical backlash to the media hype that surrounds "virtual reality." Just as the media shows signs of relenting on outlandish claims, and with the recent demise of VPL Research, the leading "virtual reality" company, it is time to reevaluate the performance of real-time interactive spatial modeling and information technologies.

Virtual worlds are multidimensional, interactive, computer-generated environments, which enable people to act in and upon a space with varying degrees of real-time interaction, as they would in the real world. These systems allow the user to enter a highly effective information environment, which heightens data awareness and understanding, and thus leads to enhanced productivity. Virtual worlds technologies are starting to find commercial applications in entertainment, manufacturing, medicine, architecture, engineering, and construction (A/E/C).

The virtual world provides some specific effects:

*U. Flemming and S. Van Wyk (eds.), **CAAD Futures '93**, pp. 513-522.*

- *Immersion*. The information environment surrounds the participant.
- *Presence*. One has a feeling of actually being in the environment.
- *Interactivity*. One has a sense of being involved in the environment.
- *Autonomy*. One is free to act and explore the environment.
- *Collaboration*. Multiple users can interact in the same world.

Humans are spatial beings. Our brains are hardwired for spatial thought, yet communicating spatial thought is often difficult. Virtual worlds facilitate the communication of complex concepts and information.

Architects, as a group, are more aware than most of the profound impact that Brunelleschi's invention of perspective had on society following the fifteenth century. Perspective initiated a fundamental change in the way humans perceive themselves and their environment. Some are looking to virtual worlds as a similar key to opening up new levels of human perception. Virtual worlds technologies are poised for deep penetration into industrial markets, especially in the A/E/C field.

2 A User Centered Approach to Current CAD / CAE / CAAD Technologies

Current CAD systems, in most cases, have not been built around the true needs of the designer. Although the software companies that manufacture these systems claim their software design was done by engineers with architectural training, these software engineers rarely have extensive hands-on experience as design professionals. The full design process has generally been neglected by the software tool makers.

Indeed, in today's architectural practice, most design activities are carried out away from the machines. CAD operators enter predetermined designs into machine-readable formats in much the way draftspersons draw up plans. Today's commercial CAD/CAE programs are most often used as drafting and rendering tools, not design tools. What little architectural design does take place on computers is often compromised by the constraints of the resident software program. The creative design process is warped by the cut/copy/paste economies of digital data.

A significant drawback of conventional CAD/CAE systems is the single-user interface. In this system one operator inputs changes. Those changes must then be sent to numerous colleagues, each of whom takes turns approving or disapproving the plans and making changes. The single-user interface creates barriers to collaboration which greatly impede design efficiency.

Current CAD systems, though inadequate for the full scope of the architectural design process, are presented in the marketplace as being very good tools. The wide market penetration of CAD/CAE has driven the prices down, thus increasing their perceived value.

Designers have accepted the shortcomings of CAD systems as inevitable, and have been relatively happy with the existing state of technology. The perception of quality software is enhanced by the speed of improvement in updated versions. Rendering takes minutes or seconds when it used to take hours or days, and the detail can be more precise than humans could conceive of producing by hand, even with unlimited time resources.

Architects are beginning to realize that they don't have to accept software tools that were handed down to them from other professions. As professionals begin to demand tools that suit the true needs of their practice, the software suppliers will be forced to respond appropriately.

3 Today's Bleeding Edge in Applied CAD/CAE/CAAD

Virtual worlds technologies are inevitable for the design professions. Industry leaders in the aerospace and automotive fields have pushed the envelope on design technologies, and new developments are finding their way into architecture, engineering, and construction. Over the past two decades, the aerospace industry adopted simulators as the preferred training tool and a great deal of the real-time interactive technology developed out of these applications.

Major players in the aerospace and auto industries have developed tools for prototyping mock-up designs in virtual space, thus decreasing product time to market. Real-time 3D modeling systems proliferate the industrial design industry. Toyota claims that their traditional design and prototype process usually takes eight to twelve months, but that they plan to use virtual worlds technology to reduce that time to three months. Northrop Aircraft and Rockwell International are using virtual mock-ups for concurrent engineering, which allows various design functions to be executed in parallel to one another.

Today, the largest A/E/C firms use expensive computerized animation or, in a few cases, interactive computer graphic walkthroughs to present designs to their clients. The animations and walkthroughs are used as rendering tools, not design tools. Designs are manipulated on traditional CAD systems, processed into rendered walkthroughs with some delay, experienced, and then designs are manipulated on the CAD system again. These systems are time consuming and very costly.

Facilities managers are allowing clients to choose from preprogrammed layouts and 3D images of office furniture. Straylight Corp., which produces PhotoVR, a software package that runs on an IBM 386, estimates that about 40 percent of its sales are to facility managers. Matsushita Kitchens is using virtual kitchen displays to sell appliances. Designers are using technology to allow their clients to participate in interior design. Expert diagnostic systems are being applied to building performance analysis in the virtual world. Major advances have been made in the area of virtual actors, agents or "bots", which are used for ergonomic studies. These synthetic people populate the virtual world in order to evaluate pre-construction, post-occupancy designs. Finally, remote sensing, telepresence, telerobotics and televirtuality technologies are being experimented with for off-site construction management, especially by the Japanese.

In 1992, the media looked at these developments and assumed that architects would immediately pick up the new technology. Some of the technology suppliers fueled the media by hyping their products. In reality, few A/E/C firms have actually gone out and purchased virtual worlds systems. There are two main reasons why A/E/C firms have not justified the intensive capital expense of setting up virtual worlds systems. First, the quality of the products that have been on the market has not been very high; and second, none of the commercial systems have been developed specifically for architects.

Until recently, the quality of real-time rendering and display has been entirely inadequate for most economically practical virtual worlds applications. The first virtual worlds demonstrations, from 1988 to 1992, were based on "glove and goggle" interfaces. The gloves are special scuba-type gloves with fiber optic wiring in them which allow the user to reach into a virtual world and manipulate computer generated objects. The goggles are special head-mounted-displays, which project 3D images onto tiny CRT screens in front of each eye and adjust the images to the user's head position, so that the virtual world completely surrounds the user. Unfortunately, the resolution in these head sets is so low that users are legally blind in most cases, and the weight of the hardware makes them difficult to wear for more than a short period of time.

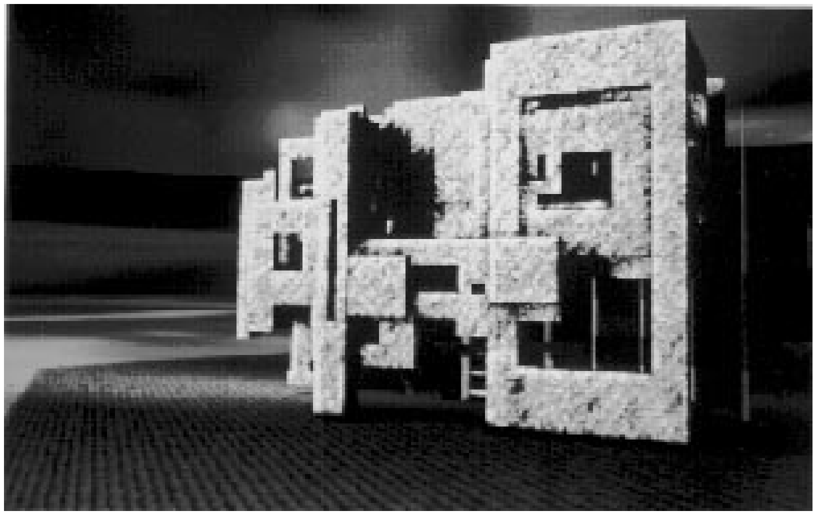

Figure 1. An algorithmically-composed object in a virtual environment from Michael Benedikt's *Cyberspace*. This image, from 1991, shows advances in resolution and image quality.

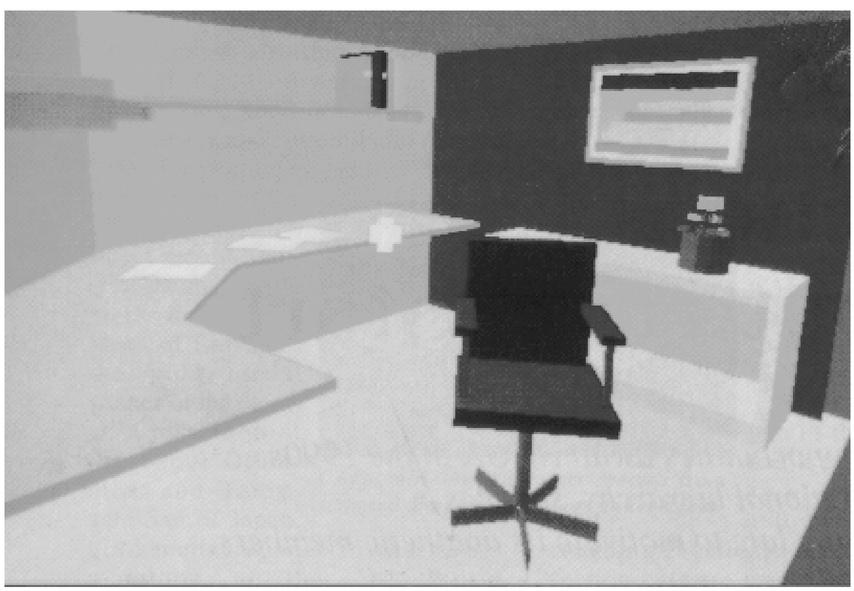

Figure 2. An early virtual worlds demo constrained by low resolution.

In 1992, many of the experts in the virtual worlds technology field began to lean away from glove and goggle interfaces toward flying mice or wands and wrap around stereoscopic video screens. A flying mouse is like a traditional mouse except that, when it is picked up off the desk, it can be used in 3D space because it tracks 6 degrees of freedom; x, y, z, roll, yaw, and pitch. Wands are used as extendible pointers in 3D space, and wrap around stereoscopic video screens are like mini omnimax theaters set up for 3D graphics.

In July of 1992, the Electronic Visualization Laboratory at the University of Illinois, Chicago, introduced a projection screen system called The CAVE (Audio-Visual Experience Automatic Virtual Environment) at the SIGGRAPH '92 Annual International Conference on Computer Graphics and Interactive Techniques. The CAVE is a 12' × 12' × 12' cubic space with display screens on each interior surface. The participant enters The Cave and is surrounded by computer imagery. The CAVE utilizes head tracking and shutter glasses to supply three-dimensionality. This interface provides one of the highest levels of presence that is available today. The sense of presence is improved by the highly immersive display, high resolution, and the least intrusive hardware that the participant has to wear. This is the type of interface is the most economically feasible for many commercial applications, and is what we have found architects are most interested in.

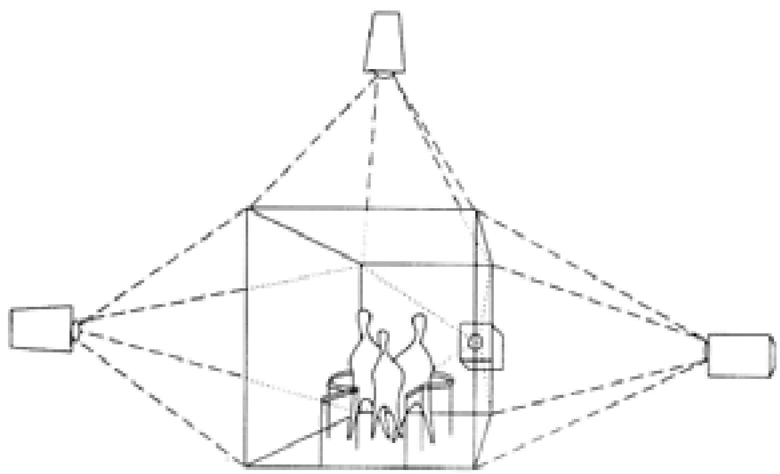

Figure 3. Diagram of a CAVE-type presentation system by Daniel Henry.

With computer resolution and rendering speeds exceeding those of conventional video, and with the single-user interface opened to multiple participants through the use of innovative input/output (I/O) devices, designers can finally begin to use the computer as a real design tool. Unfortunately, these input/output (I/O) devices are still quite expensive, and new software design tool must be developed for the interface.

There are some good low cost virtual worlds building software kits available such as Sense8's WorldToolKit, Virtus' Walkthrough, Alias Research's Cameo, and Straylight's Photo VR, but none of these systems are specialized CAAD tools. A need exists for integrated technologies that will permit real-time interactive design-on-the-fly walkthroughs, comparative space analyses of digital precedent studies, expert cost-justification programs which crunch current construction-cost figures as designs are manipulated, and expert architectural program analysis systems. This is the future Virtual Design Environment (VDE).

4 Implementing the Virtual Design Environment

Worldesign, where the author works, is a consulting firm and design studio which specializes in virtual worlds system integration and information design. We define information design as the systematic solution of our clients' information-based problems, using methodologies derived from information science, environmental psychology and design. Utilizing virtual worlds technologies, information design can go a step beyond visualization to facilitate complex data realization.

Worldesign has studied the state-of-the-art in virtual world technologies as they apply to architecture for the Japanese Ministry of International Trade and Industry (MITI). Our Japanese colleagues were interested in how virtual worlds technology would apply to their long term kansai initiative. The kansai agenda proposes human centered design and "total space planning" of "friendly" habitations and environments. Worldesign is currently expanding its client base to include domestic and international A/E/C firms, so that those clients can benefit from the knowledge gained through the MITI project.

In the summer of 1992, Dr. Robert Jacobson, Ph.D., and Rick Zobel produced a study as part of the MITI project, entitled "Building the Virtual Design Environment (VDE)." A section of the study detailed the features of an ideal VDE. I have expanded that section of the report to include why architects need these features, and how they would use them in practice.

4.1 Features of an Ideal VDE system

4.1.1 User Affordances

- *Applicable to all phases of the traditional design process*:
  1. *Architectural Program Analysis*
  2. *Preliminary and Schematic Design*
  3. *Bidding and Project Proposal*
  4. *Design Development*
  5. *Pre-Occupancy Evaluation*

  A system that is customized to all phases of the architectural design process will save time, generate better designs, minimize errors, and facilitate better communication between experts and lay people. Users will start with the system on day one of the design process, and work with the system through design development. The system will help architects understand the design constraints imposed by existing site conditions, code limitations, and program requirements. The system will then be used as a marketing tool during proposals, and finally as a design development tool.

- *Provides varying points of view at varying scale*.
  Architects need to be able to view models from a self-referential scale, and be able to modify that scale to understand usability issues. Architects will be able to walk through scale models of their designs, and will be able to modify their scale point of view to study usablity issues for small children and the disabled.

- *The ability to apply a client-centered approach to the full design process*.
  VDEs will allow architects to involve their clients more in the design process. In this way, end users of the built environment will be empowered to participate in developing quality space. An architect may schedule a number of walkthroughs for the client during the design development phase, which will improve communication and client satisfaction with the end product.
- *Enable collaborative design within plastic environments which are flexible enough to allow various experts to apply their own rules and constraints to the situation for concurrent design and engineering*.
  Architects need to be able to use the computer as a tool for collaboration, not a barrier to it. Multi-user interfaces and connectivity will improve expert participation during the design process.
- *Powerful presentation tools for walking clients through proposed designs*.
  Architects need to communicate ideas to potential clients in the most effective way possible. The VDE will give architects a competitive advantage in the bidding and project proposal stage.
- *An excellent tool for developing design constraints and program analysis*.
  Architects put considerable effort into surveying the site and analyzing the design constraints related to the site, and to the proposed use. The VDE will allow architects to keep digital records of the site in their databases, so that they have easy access to it.
- *Able to perform strong spatial precedent studies*.
  Architects need better access to precedent studies than the traditional library provides. Detailed precedent studies can be very time consuming, but they are often quite useful to good design. Eventually there will be a three-dimensional digital encyclopedia of architecture which will provide architects with quick comparative space analysis capabilities.

4.1.2 Technical Affordances

- High resolution display.
- Multi-sensory output including 3D graphics and 3D audio.
- High speed graphics and sound for real-time updates and interactivity.
- Information rich, so that the system links up to multiple relevant databases for cost and materials assessment, precedent studies, local site environmental and regional GIS studies, and demographics studies.
- Incorporating expert systems for intelligence augmentation and diagnostics.
- Flexible data structure, which enables connectivity to multiple, platforms, and databases.
- Multi-modal task-based input: voice, pen-based drawing, pointers, position sensing and tracking, and scanning, to allow for different work styles;
- Notation capabilities for audio, text, and graphical annotation and referencing of corrections, which will facilitate collaborative work;
- Multi-user interface, allows more than one operator to work within the design environment simultaneously;

• Modular software and hardware design which creates a scaleable and upgradeable system for cost efficient use. Modular components can be used independently for specific tasks, and still allows the means to enhance the system with add-on components.

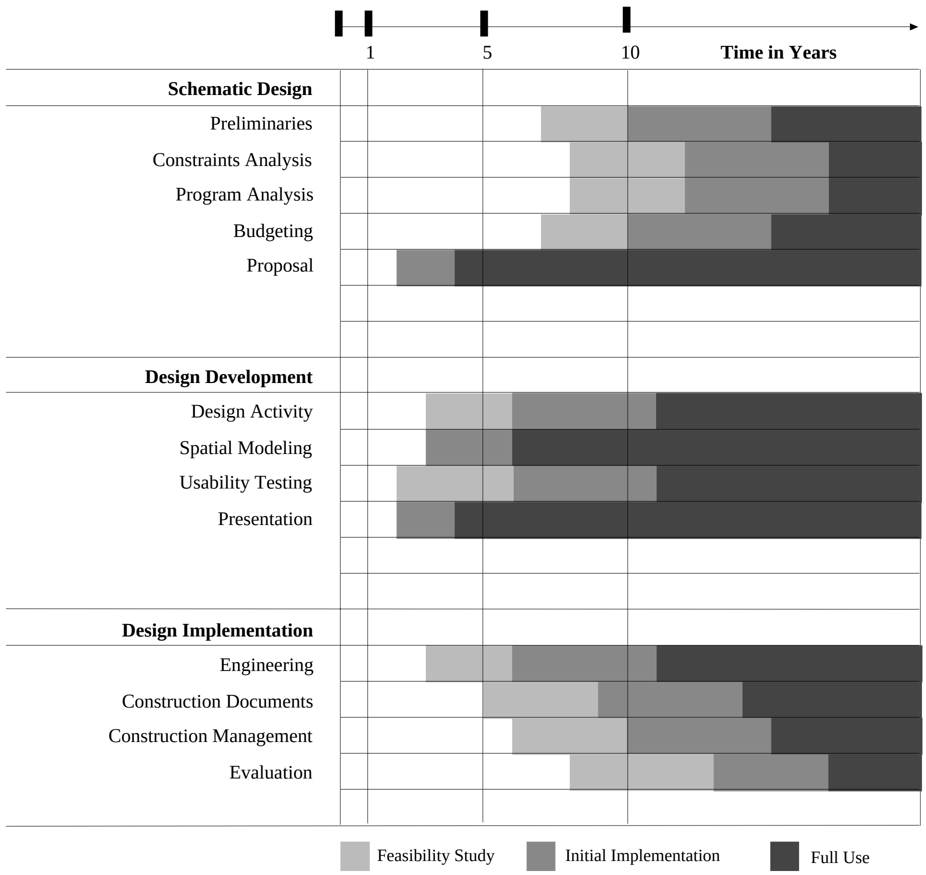

Figure 4. Diagram of Worldesign's proposed VDE development schedule.

4.2 Time Line and Technical Specifications

In the first quarter of 1993, Worldesign has begun discussions with large A/E/C firms about implementing the first phase development of Virtual Design Environments (VDE) for CAAD applications. These firms have stated that they want dual functionality out of the proposed first phase system. First, they want a high end marketing tool that they can use to present designs to their clients. The marketing/client relations function has to involve high resolution graphics, preferably with ray tracing capabilities. An immersive system can be set up with large projection screens which will supply that level of resolution, but such a system would provide little or no interactivity. The architects that we have talked to do not mind the lack of interactivity for this function. The second function that architects want is a design development tool. For this function the designers want a high level of interactivity, and they are not concerned with the resolution, as long as they can get a good spatial understanding of the environments they are developing. Worldesign expects to complete its needs assessment activities for this first phase of development in 1993, and be well into prototyping systems in early 1994.

Worldesign's strategic mission states that services lead to products, and while the company's main activities involve virtual worlds systems integration and information design, the company is forced to do some technology development. The current state-of-the-art in virtual worlds systems requires development to be done in order to service clients well. Much of the development that goes on at Worldesign will be incorporated into the ideal Virtual Design Environment (VDE). As software and procedures continue to be developed for building good virtual worlds, those systems will be used to prototype the actual built environment.

Due to cost constraints, only a few of the largest organizations in the world have the resources to apply these technologies today. The high-quality virtual world system that we are discussing with A/E/C firms right now includes three to five sets of projectors and screens at $20,000 - $40,000 each,[1] three to five (one per projector) high-end graphics workstations at $40,000 - $80,000 each, $30,000 - $50,000 for building the structure, and $20,000 - $30,000 for additional input/output hardware and software. This system will be used primarily as a marketing and presentation tool when it is initially set up. Low-end systems can be built for less than $50,000, but these systems are very limited in performance. The price of these technologies is expected to drop rapidly as virtual-worlds technology becomes more widely accepted.

5 Summary

The most important feature of an ideal VDE is that it supports collective problem solving, concurrent engineering, and collaborative project management. This can be accomplished through networked interconnectivity and multi-user interfaces. A majority of the value added through virtual worlds systems is directly related to collaborative work environments, where many experts can access and manipulate data simultaneously, in real-time. The second most important value laden feature is the 3D interface to 3D object oriented data sets. The system integrators and software engineers would take the full design process into consideration in order to implement the system at all phases of design. The system would be information rich so that it empowers the user with better decision making capabilities. Users should be able to conduct comprehensive precedent studies and comparative space analyses by interfacing with a multimedia/virtual encyclopedia of architecture. Connectivity to relevant databases, such as financial information services and geographic information systems (GIS) mapping services, as to other designers, should also be supported. The VDE gives the designer the ability to explore unlimited points of view at any scale. Expert diagnostic analysis can provide insight into energy issues, such as lighting and heating. Expert analysis should also consider human-factors issues like occupancy, circulation, and wear.

The cost of graphics engines, CPUs, and input/output devices are dropping extremely fast. The history of the computer industry shows that processing power per dollar doubles annually, and analysts expect that trend to continue throughout the 1990s. Architects have a rare opportunity to specify the next generation of CAAD systems and demand the tools that make the most sense for their practice.

[1] All prices are noted in US dollars.

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